CoMoNo: A Communication Model and Notation Supporting the Analysis and Planning of Communication Infrastructure

Vom Fachbereich Maschinenbau
der Technischen Universität Darmstadt
zur Erlangung des akademischen Grades
eines Doktor-Ingenieurs (Dr.-Ing.) genehmigte

DISSERTATION

von

Dipl.-Ing. Jan Tim Jagenberg

aus Köln

Berichterstatter:	Prof. Dr.-Ing. Reiner Anderl
Mitberichterstatter:	Prof. Dr.-Ing. Michael Abramovici
Tag der Einreichung:	29. April 2013
Tag der mündlichen Prüfung:	22. Juli 2013

Darmstadt 2014

D 17

Forschungsberichte aus dem Fachgebiet
Datenverarbeitung in der Konstruktion

Band 46

Jan Tim Jagenberg

CoMoNo: A Communication Model and Notation Supporting the Analysis and Planning of Communication Infrastructure

D 17 (Diss. TU Darmstadt)

Shaker Verlag
Aachen 2014

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at `http://dnb.d-nb.de`.

Zugl.: Darmstadt, Techn. Univ., Diss., 2013

URN urn:nbn:de:tuda-tuprints-37835
ISBN 978-3-8440-2699-3
ISSN 1435-1129

Vorwort des Herausgebers

Die moderne Informations- und Kommunikationstechnologie (IKT) bietet vielfältige Innovations- und Leistungspotenziale, die im Entstehungsprozess neuer Produkte auszuschöpfen sind. Dies setzt jedoch voraus, dass die wissenschaftlichen Grundlagen zum Einsatz der modernen IKT in der Produktentstehung vorliegen und neue Methoden wissenschaftlich abgesichert sind. Darüber hinaus stellen die wissenschaftliche Durchdringung und die Bereitstellung wissenschaftlicher Forschungsergebnisse eine abgestimmte Kooperation zwischen Forschung und Industrie dar.

Vor diesem Hintergrund informiert diese Schriftenreihe über aktuelle Forschungsergebnisse des Fachgebiets Datenverarbeitung in der Konstruktion (DiK) des Fachbereichs Maschinenbau an der Technischen Universität Darmstadt.

Ziel der Forschungsarbeiten ist die wissenschaftliche Durchdringung innovativer, interdisziplinärer und integrierter Produktentstehungsprozesse und darauf aufbauend die Konzeption neuer Methoden für die Entwicklung, Konstruktion, Arbeitsvorbereitung und Herstellung neuer Produkte.

Durch das Aufkommen der computervermittelten Kommunikation und sogenannten “Enterprise 2.0” Technologien sind die Kommunikationsintensität sowie die Anzahl der zur Verfügung stehenden Kommunikationsmedien dramatisch angestiegen. Ansätze wie Simultaneous Engineering und Concurrent Design ermöglichen komplexere Formen der Kooperation in der Produktentwicklung. Diese vielschichtige Zusammenarbeit ist in Bezug auf die sich ergebenden Anforderungen an die zugrundeliegenden Kommunikationseinrichtungen allerdings noch wissenschaftlich zu durchdringen.

Herr Jan Tim Jagenberg entwickelt in seiner Dissertation ein neues Konzept zur bedarfsgerechten Planung von Kommunikationsinfrastruktur. Das Konzept umfasst Modell und Notation zur Erfassung der Kommunikationsanforderungen und beschreibt Methoden zur Analyse und Planung. Es verbindet Ansätze der Geschäftsprozessmodellierung mit Ansätzen der Kommunikationstheorie zur Medienwahl. Diese Dissertation liefert einen wichtigen Beitrag für die durchgehende Analyse von Kommunikationsanforderungen und die darauf aufbauende Planung der Kommunikationsinfrastruktur in der Produktentwicklung.

Reiner Anderl

Vorwort des Autors

Im Laufe meiner fünfjährigen Tätigkeit als wissenschaftlicher Mitarbeiter am Fachgebiet Datenverarbeitung in der Konstruktion kam ich mit einer Vielfalt von Themen in Kontakt, welche auf die eine oder andere Weise immer mit Kommunikation zu tun hatten. Aus dem Wunsch heraus, diese fachliche Kommunikation systematisch zu durchdringen, entstand das Thema dieser Dissertation.

Meinem Doktorvater Prof. Dr.-Ing. Reiner Anderl, Leiter des Fachgebiets Datenverarbeitung in der Konstruktion der Technischen Universität Darmstadt, danke ich ganz besonders für die Betreuung dieser Dissertation. Seine weitreichende Kenntnis des Themenbereichs und seine kritischen Fragen waren sehr hilfreich und motivierend. Ich danke ebenfalls Prof. Dr.-Ing. Michael Abramovici, dem Leiter des Lehrstuhls für Maschinenbauinformatik der Ruhr-Universität Bochum, für die Übernahme des Korreferats.

Den Mitarbeitern des Sonderforschungsbereichs 666 - Integrale Blechbauweisen höherer Verzweigungsordnung - danke ich für ihre Zusammenarbeit im Rahmen der Interviews und ihre wertvollen Kommentare.

Ich danke meinen ehemaligen Kollegen für die ergiebigen Diskussionen und die kreative Arbeitsatmosphäre. Die regelmäßigen Seminare haben den Austausch mit den Kollegen wesentlich gefördert.

Meiner Familie danke ich für ihre tatkräftige Unterstützung. Insbesondere danke ich meinen Eltern, die meine Wissbegier förderten und mich schon früh dazu anregten, Dinge selbständig zu untersuchen.

Tim Jagenberg

Contents

List of Figures

List of Tables

List of Acronyms

AJAX
: Asynchronous Javascript and XML

ARIS
: Architecture of Integrated Information Systems

ASCII
: American Standard Code for Information Interchange

BPM
: Business Process Modelling

BPMN
: Business Process Model and Notation

CAD
: Computer Aided Design

CAM
: Computer Aided Manufacturing

CoMoNo
: Communication Model and Notation

CRC 666
: Collaborative Research Center 666 – Integral Sheet Metal Design with Higher Order Bifurcations – Development, Produc-

tion, Evaluation

DFG
German Research Foundation

DMS
Document Management System

DMU
Digital Mock-Up

DSS
Decision Support System

eEPC
Extended Event-driven Process Chain

EPC
Event-driven Process Chain

GSM
Global System for Mobile Communications

GSS
Group Support System

IDEF
Integration Definition

IEEE
Institute of Electrical and Electronics Engineers

OMG
Object Management Group

POSIX
Portable Operating System Interface

REST
: Representational State Transfer

RSS
: Really Simple Syndication

SAAS
: Software-as-a-Service

SMS
: Short Message Service

SOAP
: Simple Object Access Protocol

UML
: Unified Modeling Language

VDA
: German Association of the Automotive Industry

VDI
: Association of German Engineers

XML
: eXtensible Markup Language

Chapter 1

Introduction

Most people will have experienced situations in which communication did not work out as expected: Multiple colleagues work collaboratively on a document that is sent forth and back by email, until the very last one has completely lost track which version contains the last changes. Someone sends an important email and never receives the expected feedback, because it ended up being filtered. Two colleagues, located in different parts of the same city, try to exchange a file, but file attachments to emails are blocked for security reasons. The only remaining medium available to them is a web-conferencing system, which forces them to be online at the same time. Scenarios like these highlight that the choice of available communication media has a strong impact on the outcome of the communication.

The amount of exchanged information and the choice of possible communication media in engineering increased dramatically because of the rise of computer mediated communication and web 2.o technologies in the recent decades. While many people have adopted a broad range of new communication tools in their personal life, the

application of these technologies in enterprise environments is lagging behind. Preceding this development, scholars from various domains started to look at the phenomenon communication from a scientific perspective. From the early mathematical models of Hartley in 1928 to Craig's declaration of the "Communication Theory as a Field" in 1999 more than seven decades passed in which this new field developed. Critical Mass Theory analysed the usage patterns involved in the adoption of interactive media while Media Rich Theory, Media Synchronicity Theory, Task-Technology-Fit Theory, and Enterprise 2.0 study the selection of appropriate media.

Product development approaches like simultaneous engineering, concurrent design, and the management of trust between cooperation partners enable more complex processes. The resulting lower depth of in-house development in turn leads to an increase in communication intensity and complexity.

This increasing elaborateness of interactions in businesses led to the development of new business process modelling approaches. Standards like the Business Process Model and Notation (BPMN) enable automated evaluation of the interactively created models. Although BPMN includes models and diagrams focussing on communication processes, they only capture very basic information.

Because of the increasing intensity and complexity of communication in product development, it is necessary to improve the way communication processes and the related infrastructure can be analysed and planned. This dissertation argues that neither media selection theories nor business process modelling alone can offer the benefits an integrated approach can deliver. For a comprehensive analysis of communication processes and the related communication in-

frastructure, aspects from both fields need to be amalgamated.

The concept presented here defines a Communication Model and Notation (CoMoNo) based on the BPMN conversation diagram with extended communication characteristics derived from Media Richness Theory, Media Synchronicity Theory, Task-Technology Fit Theory, and the Enterprise 2.0 approach. Based on the extended model and notation, the concept provides methods for the analysis of communication processes and the planned introduction of appropriate communication media.

A prototypical implementation of the CoMoNo concept was applied to a case study at the Collaborative Research Center 666 – Integral Sheet Metal Design with Higher Order Bifurcations – Development, Production, Evaluation (CRC 666). In a series of interviews, the communication processes of the CRC 666 were captured in order to support the evaluation of the proposed model, notation, and methods. 16 of 18 interviewees judged the model and notation as helpful during the interview. 17 considered the notation as easy to understand. According to the analysis based on the gathered data, the CRC 666 has a generally well-adapted communication infrastructure, which could benefit from blogging or a desktop video-conferencing solution.

This dissertation is structured into the following chapters: Chapter 2 describes the current state in the areas of product development, communication theory, and business process modelling and highlights the necessity for an integrated approach. In Chapter 3 the goals and requirements against which the proposed concept is evaluated are established: Enhanced modelling and analysis of communication processes in order to support the planning of communication infras-

tructure. Building on this basis, Chapter 4 describes the conceptual CoMoNo approach to integrate business process modelling with aspects of communication theory. It defines the model and notation as well as the derived analysis and planning methods. This chapter also includes the verification of the concept against the previously defined requirements. A prototypical implementation of the concept is presented in Chapter 5, which also examines the results of a case study that applied the CoMoNo concept at the CRC 666. Future opportunities for research are highlighted in Chapter 6 after which the concluding summary is provided in Chapter 7.

Chapter 2

Current State

This chapter provides the theoretical foundation on which the concept described in Chapter 4 is based. The three central areas of interest around which the concept revolves are product development, communication theory, and business process modelling.

The first section focusses on how current practices in product development like product-life cycle management, simultaneous engineering, concurrent design, trust management, and agile methods increase the need for coordination and thus communication.

The current state of communication theory as a scientific field is explained in the beginning of the second section. The section then proceeds by introducing the critical mass theory, which explains how the use of newly available communication media propagates in a group of potential users. Next, the media choice theories are described, which aim to understand why people choose certain communication media in a specific context. Following this, the central aspects of the Web 2.0 and Enterprise 2.0 concepts are broken down, as many of these are relevant to modern, so called social, commu-

nication media. Finally the section on communication theory offers a breakdown of contemporary communication media, their historic background, and their application.

The third section of this chapter introduces the concept of Business Process Modelling (BPM). After a brief look at the history of BPM methods, today's established standard BPMN is illustrated. The final part of this section deals with the impact of communication orientation in process modelling and explains why a stronger focus on communication modelling improves the results of business process re-engineering.

The final section reviews the current state and shows that the lack of integration between the three domains product development, communication theory, and business process modelling has left open issues, which are addressed by the concept proposed in Chapter 4.

2.1 Product Development

The organisational structure of product development changed in recent years because of globalisation. The spatial and temporal divide requires increased coordination and communication during the development of new products. The virtualisation required to work in global product development teams leads to further integration of cooperation, coordination, and communication technologies into the design processes [AVR08; ARV09; AG11].

Following market and technological developments, the challenges involved in product development undergo constant change. In their work on complexity in product development, Lindeman et al. identify four main drivers of complexity: the market, the prod-

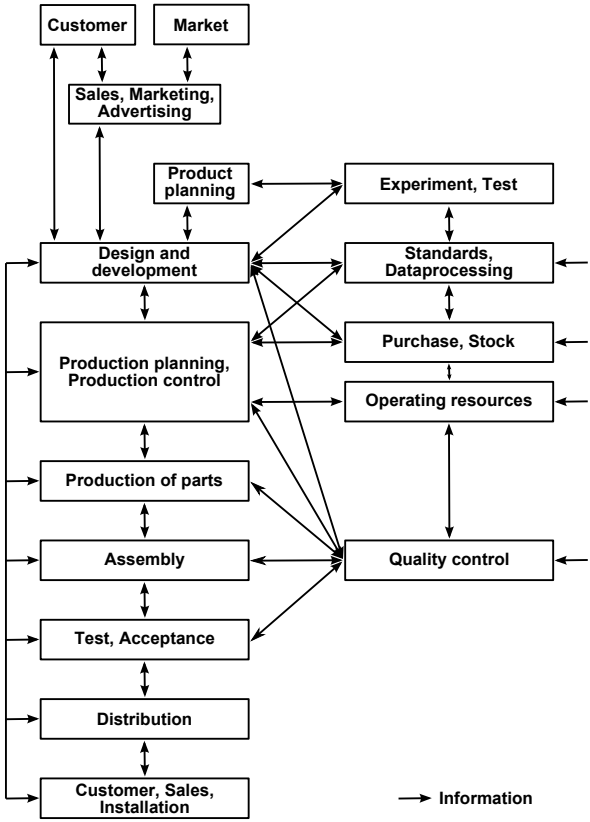

Figure 2.1: Information flows between departments [PWB07]

uct, the processes, and the organisation [LMB09]. The focus of market demand shifted from a few hits at the broad end of the distribution towards its long tail of mass customisation [PD99]. The new demand for more variants and selectable configuration details in turn increased the complexity of products. Consequently the complexity of the processes and the organisations had to adapt to this challenge with increased division of labour, multi-disciplinarity, and need for coordination [LMB09].

In order to provide a solid foundation in this highly dynamic environment, formalisations of the product development process have been established. For example, the generic problem solving process proposed by the Association of German Engineers (VDI), the Association of German Engineers, provides a domain agnostic framework for the methodical development and design of technical products. It defines common development steps and a common nomenclature and follows a hierarchical approach by decomposing a complex problem into multiple smaller and easier to solve sub-problems [VDI93].

The central role of product development in the overall process is highlighted by its various links to other departments of a business. As can be seen in Figure 2.1, the design and development department is the most interconnected department [PWB07].

2.1.1 Simultaneous Engineering, Concurrent Engineering, and Concurrent Design

The meaning of the terms “Simultaneous Engineering” (SE), “Concurrent Engineering”, and “Concurrent Design” is rather similar and a clear differentiation difficult. In their early definition, Winner et al. use the term concurrent design to describe one of the aspects, which

concurrent engineering, according to them, focusses on: The integrated design of products and processes.

> "Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements" [Win+88].

This definition of concurrent engineering has been refined by Cleetus giving it a stronger focus on team values such as cooperation, trust, and sharing. According to him,

> "[...] CE, for all the top management commitment that might back it up, will fail if the organization, at all levels, does not embrace the norms of team working and learn to live by them each day" [Cle92].

The synonymous term "simultaneous engineering" seems to stem from the British context and is specifically acknowledge by Anumba and Evbuomwan in their review of literature. According to them, the main achievements of concurrent engineering are that the "[...] principles [would] also facilitate concurrency in project development, enable early resolution of conflicts, ensure buildability, and permit safety and risk analyses to be carried out at an early stage" [AE97].

Also using the term simultaneous engineering, Eversheim et al. define the aims as:

> "Reducing the time to market, i.e. the time period between the conception and the launch of the product, trimming development and manufacturing costs; and enhancing the quality of products in the general sense of Total Quality Management" [Eve+97].

According to Eversheim, it achieves this by deviating from sequential working procedures and running product and process modelling in parallel instead.

Pahl states that "[...] the activities of the various departments run in parallel or at least have significant overlap. Intensive contacts with customers are encouraged, many suppliers are integrated in the process, [...] and the product is monitored until the end of its working life" [PWB07] (see Figure 2.2).

Talukdar et al. define the term concurrent design in a narrower sense as the conflict-free integration of individual design tasks:

> "Given: a number of design tasks in which each task can have several input aspects, some that are independently specified, others that are computed by previous tasks;
> Find: (1) a path to perform each task;
> (2) a means for integrating these individual task-paths into a composite path such that all the input and output aspects are consistent (conflict free).
> Thus, in essence, the concurrent design problem is one of conflict-free, path integration" [TF91].

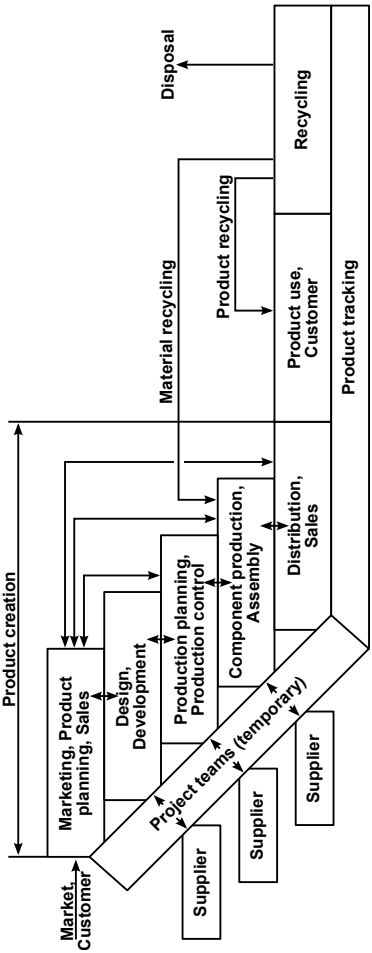

Figure 2.2: Simultaneous engineering [PWB07]

In their definition of an “interdisciplinary concurrent design methodology”, Smailagic et al. emphasise the importance of concurrency by stating: “The goal of the design methodology is to allow as much concurrency as possible in the design process. Concurrency is sought in both time and resources” [Sma+95].

Based on the above definitions, concurrent design should be considered an element of simultaneous engineering, which specifically enables sub-tasks to be handled more or less independently, by defining and optimising their boundaries and interfaces.

As made clear by Pahl, Simultaneous Engineering is not confined to the boundaries of a single organisation. It often integrates customers and suppliers, which necessitates early coordination between the partners. In practice, this coordination is often neglected or done late during the cooperation which results in problems being identified too late [VDA12]. In order to simplify the coordination, the German Association of the Automotive Industry (VDA) published a recommendation, which specifies different models of cooperation and provides a checklist for the matching of communication and computer infrastructure [VDA12].

The responsibility for the application of this recommendation lies with the project leader and the overall process is structured into three phases: pre-phase, implementation phase, and post-phase. During the pre-phase, the individual roles, the model of cooperation, and the checklist are defined and the SE-team is deployed. During the implementation phase, the checklist is integrated with the relevant legal documents and kept up-to-date according to the progress of the project. Regular review meetings ensure that all involved parties share the same basis. In the post-phase, the gained experience is doc-

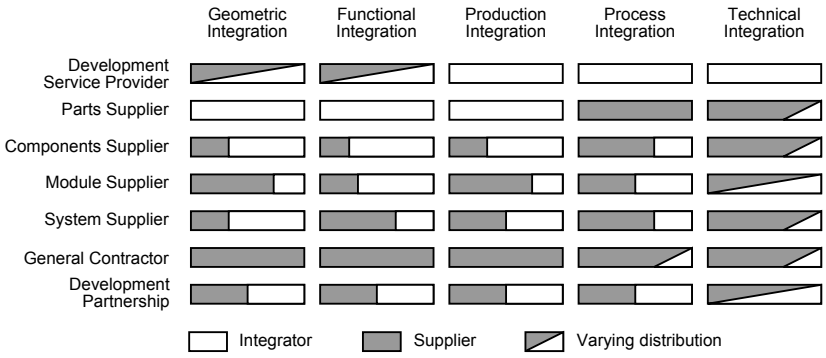

Figure 2.3: Overview cooperation models [VDA12]

umented and the specific checklist is adapted accordingly.

In order to propose appropriate models of cooperation, the recommendation introduces the concept called “depth of integration”, which specifies to what extend the supplier is integrated into the product creation process. Moreover, five types of integration are differentiated: geometric integration (e.g. Digital Mock-Up (DMU)), functional integration (e.g. integration of audio and navigation), production integration (e.g. assembly testing), process integration (e.g. adaptation to the integrator processes), and technical integration (e.g. exchange of data).

Based on these two aspects, seven models of cooperation are identified: Development Service Provider, Parts Supplier, Components Supplier, Module Supplier, System Supplier, General Contractor, and Development Partnership. Figure 2.3 explains the varying levels of integration between these models. Common to all these models is that all cooperation requires a considerable amount of information exchange. It is considered of such value, that already one of the first sections of the checklist template (A.3.) defines the com-

munication media to be used during the cooperation.

Another important factor regarding the communication and cooperation in Simultaneous Engineering projects is the protection of the intellectual property of each participant and thus the trust between the partners. The recent research project “TRUST - Teamwork in interorganisational cooperations” defines trust as subjective, asymmetric, context and situation dependent, dynamic, and not transitive [VAK13]. The empirical data show, that employees are often unsure which information they are allowed to pass on to the cooperation partner. The TRUST project targets this problem by integrating a decision support tool based on a trust model into a cooperation management platform. The model takes attributes of the cooperation as well as experiences and the reputation of the cooperation partner into account in order to predict the appropriate level of trust. In combination with a risk assessment, the tool uses this prediction in order to propose adequate intellectual property protection profiles for the exchange of information. The individual employees are thus supported in their assessment and the decisions and information exchanges become traceable.

Summarising the findings about Simultaneous Engineering presented above, it can be said that this approach increases the intensity and complexity of information exchanges. As highlighted in the TRUST project, this development makes adequate analysis and management approaches for communication necessary.

2.1.2 Agile Methods in Product Development

Agile project management methods originally emerged in software engineering and have seen wide acceptance in this field [WG12]. Re-

cently agile methods like Scrum have been adapted to adjacent fields like mechatronics or industrial engineering [Yan+10]. The agile approach specifically values individuals and interactions, working software, customer collaboration, and responding to change [Bec+01].

Scrum, the most successful agile method, follows an iterative and incremental approach and is driven by cross-functional teams [WG12; Dee+12] (see Figure 2.4). The central element of the method is the *Sprint*, which structures the development process in cycles of work. Each sprint is between one and four weeks long, and is timeboxed, i.e. it is neither shortened nor extended. Two essential planning tools are the *Product Backlog* and the *Sprint Backlog*. The former contains a prioritised list of customer requirements or user stories, while the latter is a list of tasks derived from the user stories. The *Product Owner* controls the product backlog and the *Team* controls the Sprint Backlog. At the beginning of each sprint, the team decides which items from the product backlog should be implemented in this iteration and the sprint backlog is filled with the according tasks. The team briefly meets on a daily basis in order to check the progress and possibly adjust the next steps. After each sprint, the increment is delivered to the customer and the past sprint is reviewed with the *Stakeholders*. In order to support this process, Scrum defines a facilitator, the *Scrum Master*, who helps the team to learn and apply the method and who does whatever is necessary to support the team, the product owner, and the organisation in order to be successful. The scrum master is neither team leader nor project manager, but serves the team by removing impediments, protecting the team from outside interference, and guiding the product owner, team and the organization.

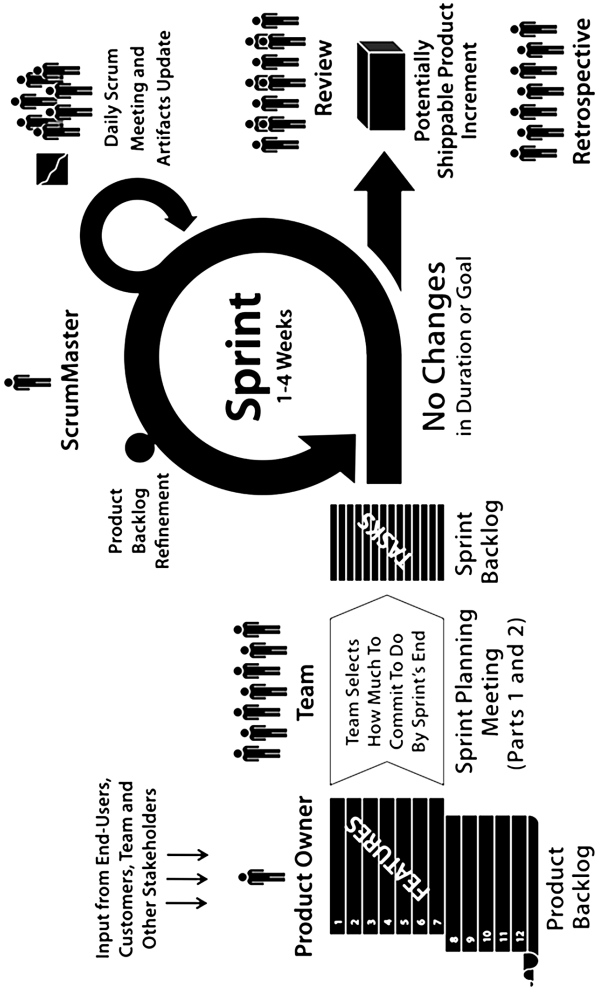

Figure 2.4: Scrum overview [Dee+12]

The focus of Scrum is on delivering a product, which is integrated, fully tested, end-user documented, and potentially shippable at the end of each sprint. The self-organising nature of Scrum leads to a strong emphasis on communication and collaboration. A good understanding of the communication requirements of the involved parties further facilitates the Scrum process [Sut+07].

The adoption of more agile project management approaches in the industrial field will lead to increased communication between the team members and will shift their specific needs for communication media.

2.2 Communication Theory

Upon reading into the field of communication theory, one quickly realises the heterogeneous structure of this topic. Anderson analysed seven texts offering an overview of communication theory and counted the proposed communication theories. Of the 249 nominations, 195 only appeared in a single publication and just eighteen in three or more. The most widespread theory was named in five publications [And96].

2.2.1 Communication Theory as a Field

In his seminal paper, Craig argues, that the basis for this incoherence, is the multidisciplinary origin of the field [Cra99]. The proposed list of origins includes diverse fields such as literature, mathematics, engineering, sociology, psychology, anthropology, and zoology. The resulting interdisciplinarity is seen as both, a meritorious quality as well as an obstacle on the path towards a coherent communication theory.

In order to reconstruct communication theory as a field, Craig proposes the goal of a dialogical-dialectical coherence, a state in which the community actively argues about commonalities and debates differences: “Productive theoretical arguments most readily occur within an interpretive community sustained by a disciplinary matrix, a background of assumptions shared in common. Disciplinarity, however, does not require that diversity and interdisciplinarity be suppressed.”

Over the course of his paper, he introduces seven traditions of communication theory: rhetorical, semiotic, phenomenological, cybernetic, sociopsychological, sociocultural, and critical. He highlights their defining aspects (see Table 2.1) as well as their possible differences. As the proposed classification provides a helpful orientation regarding the various communication related theories, each tradition will be briefly introduced.

The rhetoric tradition focusses on the practical aspects of public communication and discourse. It systematically studies methods of communication and how they influence public judgement and decision. In doing so it enables the producer of public communication to develop more effective rhetoric and at the same time allows the consumer more critical judgements by understanding the used rhetoric. A central and on-going dispute within the tradition is whether it should be considered a good, bad, or plain neutral tool.

The semiotic tradition is the study of signs as means to mediate between subjects. Signs are considered in a very broad sense like languages or other sign systems like pictograms (consider “a picture is worth a thousand words”). The central theme of the tradition is thus the presentation of meaning and its transmission. Even the medium

	Rhetorical	**Semiotic**	**Phenomenological**	**Cybernetic**	**Sociopsychological**	**Sociocultural**	**Critical**
Communication theorized as:	The practical art of discourse	Intersubjective mediation by signs	Experience of otherness; dialogue	Information processing	Expression, interaction, & influence	(Re)production of social order	Discursive reflection
Problems of communication theorized as:	Social exigency requiring collective deliberation and judgment	Misunderstanding or gap between subjective viewpoints	Absence of, or failure to sustain, authentic human relationship	Noise; overload; undertoad; a malfuction or "bug" in a system	Situation requiring manipulation of causes of behavior to achieve specified outcomes	Conflict; alienation; misalignment; failure of coordination	Hegemonic ideology; systematically distorted speech situation
Metadiscursive vocabulary such as:	Art, method, communicator, audience, strategy, commonplace, logic, emotion	Sign, symbol, icon, index, meaning, referent, code, language, medium, (mis) understanding	Experience, self & other, dialogue, genuineness, supportiveness, openness	Source, receiver, signal, information, noise, feedback, redundancy, network, function	Behavior, variable, effect, personality, emotion, perception, cognition, attitude, interaction	Society, structure, practice, ritual, rule, socialization, culture, identity, coconstruction	Ideology, dialectic, oppression, consciousnessraising, resistance, emancipation
Plausible when appeals to metadiscursive commonplaces such as:	Power of words; value of informed judgement; improvability of practice	Understanding requires common language; omnipresent danger of miscommunication	All need human contact, should treat others as persons, respect differences, seek common ground	Identity of mind and brain; value of information and logic; complex systems can be unpredictable	Communication reflects personality; beliefs & feelings bias judgements; people in groups affect one another	The individual is a product of society; every society has a distinct culture; social actions have unintended effects	Self-perpetuation of power & wealth; values of freedom, equality & reason; discussion produces awareness, insight
Interesting when challenges metadiscursive commonplaces such as:	Mere words are not actions; appearance is not reality; style is not substance; opinion is not truth	Words have correct meanings & stand for thoughts; codes & media are neutral channels	Communication is skill; the word is not the thing; facts are objective and values subjective	Humans and machines differ; emotion is not logical; linear order of cause & effect	Humans are rational beings; we know our own minds; we know what we see	Individual agency & responsibility; absolute identity of self; naturalness of the social order	Naturalness & rationality of traditional social order; objectivity of science & technology

Table 2.1: Seven traditions of communication theory [Cra99]

itself can become a message, for example, a letter wrapped around a stone, thrown through a window. While this message could hardly be misunderstood, other symbols can easily be misinterpreted by a different person.

The phenomenological tradition considers the experience of identity and difference and the resulting dialogue. It bridges the dualism of subject and object by considering both as subjects. The resulting unmediated contact is seen as a necessary human experience, which can easily degrade to inauthenticity. An interesting aspect of phenomenology is probably known to most people: Conscious planning of communication, with however benevolent goals, often reaches the exact opposite and hinder an actual dialogue. Similar common are experience where two persons achieve an instant understanding beyond words.

The cybernetic tradition sees processing of information as the central theme and focusses on the functionality of complex systems. The tradition considers communication as mere information processing and it becomes possible to analyse various forms of communication from the same perspective. This includes intrapersonal communication, interpersonal communication, group communication, and even communication with artificial entities such as robots. Having roots in systems science, the cybernetic tradition emphasises problems of complexity and the possibility of non-linear behaviour. It also implies that the whole is greater than the sum of its parts.

The sociopsychological tradition is based in experimental science. It explains reasons and results of social behaviour. It attempts to control these behavioural causes and effects. In this context, the reaction to communication with others is influenced by attitudes,

emotional states, personality traits, or unconscious conflicts. Irritatingly, the sociopsychological tradition demonstrates how our judgements can be influenced by social context, beliefs, and emotions. This irrationality challenges our perception of autonomy.

The sociocultural tradition analyses the macro-level phenomenon of social order and how it is created, sustained, and transformed by interaction processes on the micro-level. The two antipodes of this tradition are structural theories based on macro-level patterns and the interactionist theories focussing on micro-level processes. Central themes of the sociocultural traditions are technological change, change of social orders, urbanisation, bureaucracy, and globalisation.

The critical tradition tries to achieve truth through dispute, which it induces by asking questions that provoke critical reflection. A central aspect of the critical tradition is social injustice based on self-perpetuating ideologies such as racism and patriarchy. It challenges the moral-political neutrality and objectivity of science, the central role of individualism, the naturalness of social order, the validity of authority, and the legitimacy of tradition.

Applying the discursive approach of the critical tradition to communication theory itself, is the exact meta-discourse Craig is trying to initiate with his clarification of traditions, their similarities, and their potential differences. By providing a common nomenclature and structural matrix of communication theory, the individual traditions are encouraged to sustain a productive discourse.

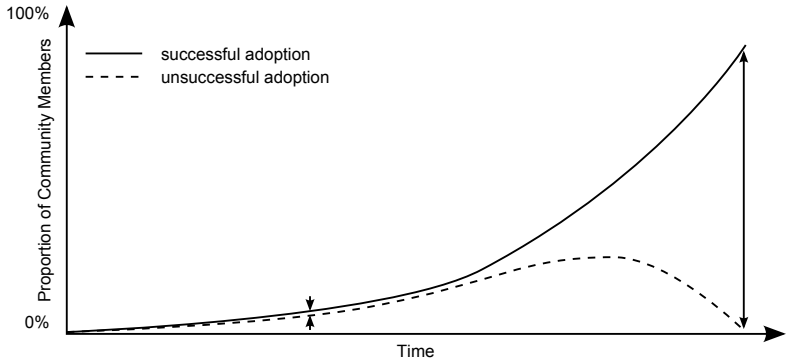

Figure 2.5: Critical mass theory - media adoption[Mar87]

2.2.2 Critical Mass Theory

Markus' critical mass theory of interactive media offers explanations how media usage patterns develop within communities. Markus considers "universal access" as the essential factor for the success of interactive media in a group of users. If only some users adopt a new technology, the community risks disintegrating into two subgroups, adopters and non-adopters. In the case of limited access, the adopters cannot receive the full benefits of the new medium, as the non-adopters are not available.

When comparing interactive media to other technologies, there are two types of dependency between the users: sequential and reciprocal. For the former, only late adopters are affected by the actions of the early adopters, while for the latter, early adopters are also affected by the lack of availability of the late adopters. In interactive media, early adopters only receive low benefits at high costs, conversely late adopters receive higher benefits at sometimes even lower costs, as the technology matures. Markus considers the production function

the underlying principle of this effect. It specifies the relationship between the contributions of resources and the achievement of the common good. In the case of a decelerating production function, the initial contributions affect the public good most, while succeeding contributions trail off. The inverse is true for an accelerating production function: Later contributions generate larger gains.

Another aspect Markus considers essential for interactive media is the heterogeneity of resources and interest. The probability of a few highly interested and highly resourceful users being available increases when there is heterogeneity. As an accelerating production function only offers small gains for the initial contributions, these specific users are essential for the progress of adoption.

Markus draws five central conclusions from the principles detailed above: Interactive media usage can reach two states in the long run, full adoption or demise. A tiny difference in the number of early adopters can make the difference between the two states (see Figure 2.5). The lower the resources each adopter must contribute to keep the medium useful, the higher the probability of universal access for the given community. The more heterogeneous the users of a community are regarding resources and interests, the higher the probability of a successful adoption. High-interest, high-resource users are very important among the early adopters in order to achieve universal access. Measures that support the general interest and availability of resources will promote full adoption in a community.

2.2.3 Sender, Message, and Receiver

In his work towards a quantitative measure of information, Hartley defines the basic constituents involved in communication: sender,

listener, and symbols, which convey a meaning according to a general agreement. The process of communication is considered a repeated selection of symbols, where each successive selection eliminates more possible symbols and thus makes the information more precise [Har28]. Hartley distinguishes between the number of primary symbols s and the number of secondary symbols s_2 which are made up from n_1 selections of primary symbols. For the American Standard Code for Information Interchange (ASCII) this resolves to $S_1 = 2$, $n_1 = 7$, and $s_2 = s^{n_1} = 128$. A selection of n_2 secondary characters results in $s_2^{n_2} = s^{n_1 n_2}$ possible sequences. The same number of possible sequences could have been generated by $n = n_1 n_2$ selections of primary symbols, which shows that the grouping of primary symbols into secondary ones does not affect the number of possible selections.

Hartley proceeds by defining the amount of information H as proportional to the number of selections $H = Kn$. By assuming that two systems with the same number of selections carry the same amount of information, Hartley derives the measure of information as the logarithm of the number of possible sequences:

$$s_a{}^{n_a} = s_b{}^{n_b} \tag{2.1}$$

$$H = K_a n_a = K_b n_b \tag{2.2}$$

$$\frac{K_a}{\log s_a} = \frac{K_b}{\log s_b} \tag{2.3}$$

$$K = K_0 \log s \tag{2.4}$$

$$H = n \log s = \log s^n \tag{2.5}$$

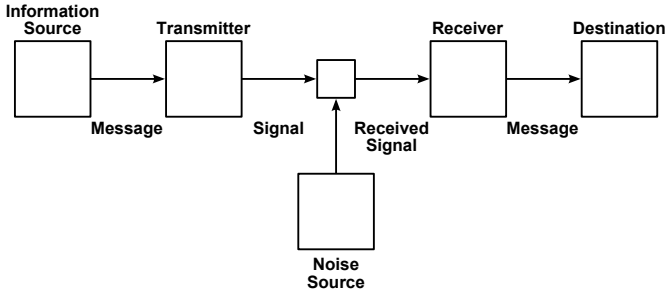

Figure 2.6: Schematic diagram of a general communication system [Sha48a]

Because the constant K_0 can be arbitrary, he omits it and chooses the logarithmic base 10. As a reference to his contribution, the unit of this measure is called a “hartley”. Using base 2 the unit is called a “bit” and using base e it is called a “nat” [Rez61].

While Hartley does not elaborate more on symbols and their meaning, Morris focusses on these and provides a foundation for semiotics. He identifies three essential concepts: the sign vehicle “that which acts as a sign”, the designatum “that which the sign refers to”, and the interpretant “that effect on some interpreter in virtue of which the thing in question is a sign to that interpreter”. He identifies three fields of study related to these core concepts: syntactics, semantics, and pragmatics. While syntactics examines the relations of signs to one another, semantics analyse the relations between signs and the objects, which they denote. Lastly pragmatics considers the relations between signs and their interpreters [Mor38].

Based on the concepts developed by Hartley, Shannon developed a mathematical theory of communication, which later became the foundation to the field of information theory. In his work, he clearly

distanced himself from dealing with the meaning of messages, but he introduced a general model of a communication system (see Figure 2.6) which has provided the basis for numerous adaptations until today[Sha48a; Sha48b]. According to Shannon, a general communication systems contains the following elements: An information source providing the message or messages to be communicated to the destination, a transmitter producing a signal from the message, a channel transmitting the signal from transmitter to receiver, a potential source of noise distorting the signal, a receiver deriving the message from the signal by applying the inverse function of the transmitter and a destination for which the message is intended.

Based on this model, Shannon analyses the entropy of an information source , the capacity of a channel, and the impact of noise on the channel capacity [Sha48a]. Based on the work of Hartley, he defines the entropy of a discrete source as

$$H = -K \sum_{i=1}^{n} p_i \log_2 p_i \tag{2.6}$$

where $p_1, p_2, \ldots, p_i$ are the probabilities of occurrence for a set of possible independent events and K is an arbitrary positive constant. Because Shannon uses the logarithmic base 2, the unit of this entropy is bits per symbol. The entropy, and thus the uncertainty, is maximised, when the individual probabilities are equal. The noise-free channel capacity C is measured in bits per second and is limited by the rate of information transmission R measured in symbols per second. In the case of a noisy channel, the conditional entropy of the input when the output is known $H_y(x)$ needs to be subtracted from the noise-free entropy of the source $H(x) - H_y(x)$.

If, for example, information were transmitted at 1000 symbols per second with two equally possible symbols, the noise-free capacity would be:

$$C = RH = 1000 \frac{symb.}{sec.} \times -\left(\tfrac{1}{2}\log_2 \tfrac{1}{2} + \tfrac{1}{2}\log_2 \tfrac{1}{2}\right) \frac{bits}{symb.} = 1000 \frac{bits}{sec.} \quad (2.7)$$

If noise during transmission on average changes 1 in 100 symbols, the conditional entropy and capacity evaluate to:

$$H_y(x) = -\left(\tfrac{99}{100}\log_2 \tfrac{99}{100} + \tfrac{1}{100}\log_2 \tfrac{1}{100}\right) \frac{bits}{symb.} = 0.080793 \frac{bits}{symb.} \quad (2.8)$$

$$\begin{aligned} C &= R * \left(H(x) - H_y(x)\right) \\ &= 1000 \frac{symb.}{sec.} \times (1.0 - 0.080793) \frac{bits}{symb.} = 919.207 \frac{bits}{sec.} \end{aligned} \quad (2.9)$$

This example highlights, that even if only 1 per cent of the symbols is changed by noise, this has a way larger impact on the capacity. If 50 per cent of the symbols were potentially changed, the capacity would drop to 0.

Already before this work, he was deeply involved in the early developments of boolean and information theory. In his master thesis at the Massachusetts Institute of Technology, he devised a concept to simplify the arrangement of electromechanical relays based on boolean algebra and binary arithmetic. In this work, he also proved that it would be possible to use combinations of electromechanical relays to tackle boolean algebra problems [Sha36].

In the introductory note to the revised version of Shannon's mathematical theory of communication, his co-author Weaver opens the engineering details to a wider audience and defines communication as "[...] all the procedures by which one mind may affect another." In

an even broader sense, he considers communication "[...] the procedures by means of which one mechanism affects another mechanism" [SW64].

Summarising the above, communication is the process of transmitting a message from a sender to a receiver by means of a signal. Both sender and receiver can be either concrete persons or abstract entities. The message itself consists of symbols, which in turn have a syntactical relation to one another, a semantic relation to the object they refer to, and a pragmatic relation to the receiver.

2.2.4 Media Richness Theory

In their work on information processing in organisations, Daft and Lengel introduce the concept of "Information Richness" and elaborate how it affects organisation on different levels. They develop models for managerial behaviour and information processing in organisations and reinterpret traditional organisational concepts in the light of their new framework [DL84; DL86; DLT87].

Based on the proposition that human languages differ in their ability to convey information they introduce the measure of media richness. They differentiate between communication media of high richness and low richness. The new measure media richness is an aggregate of four properties: feedback capability, communication channels utilised, source, and language. Different communication media are placed on a 5-step scale following their media richness (see Table 2.2).

In their models of managerial and organisational information processing, Daft and Lengel derive the conclusion that "rich media enable people to interpret and reach agreement about difficult, hard

Richness	Medium	Feedback	Channel	Source	Language
Highest	Face-to-Face	Immedi-ate	Visual, Audio	Personal	Body, Natural
High	Telephone	Fast	Audio	Personal	Natural
Moder-ate	Written, Personal (mail, memos)	Slow	Limited Visual	Personal	Natural
Low	Written, Formal (bulletins, documents)	Very Slow	Limited Visual	Imper-sonal	Natural
Lowest	Numeric Formal (computer output)	Very Slow	Limited Visual	Imper-sonal	Numeric

Table 2.2: Characteristics of media that determine richness [DL84]

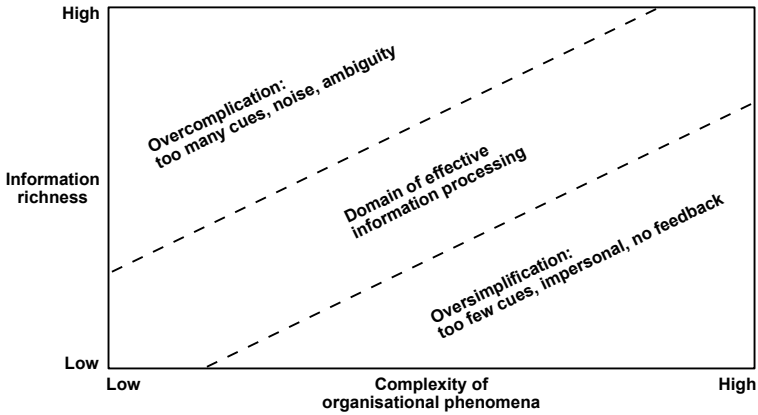

Figure 2.7: Model of manager information processing [DL84]

to analyse, emotional, and conflict-laden issues" while "media of low richness are appropriate for communicating about routine activities" (see Figure 2.7).

2.2.5 Media Synchronicity Theory

As a reaction to the not convincing empirical tests of media richness theory, Dennis and Valacich proposed a new theory instead of refining media richness theory: media synchronicity theory [Den+98; DK98; DV99]. They define a set of capabilities for communication media, namely immediacy of feedback, symbol variety, parallelism, rehearsability, and reprocessability (see Figure 2.8). Moreover they consider the categorisation of tasks which media richness theory provides as too coarse and suggest a two-dimensional categorisation. One dimension differentiates between the task functions production, group well-being, and member support while the other dimension discriminates between the communication processes convergence

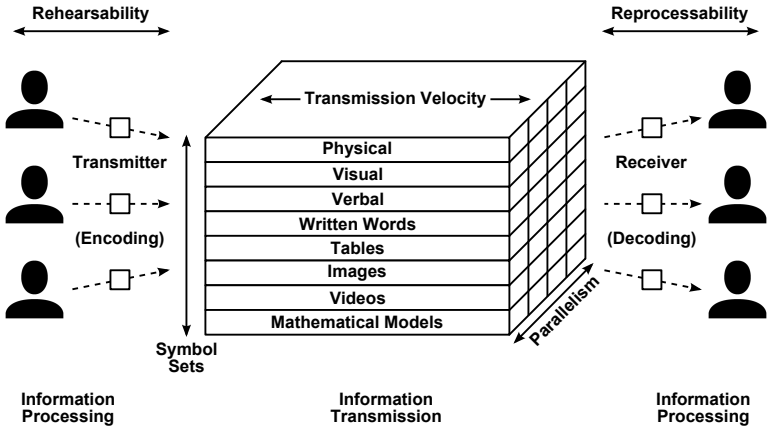

Figure 2.8: Communication system and media capabilities [DFV08]

and conveyance. Dennis and Valacich consider both of the latter as equally important: "Without adequate conveyance of information, individuals will reach incorrect conclusions. Without adequate convergence, the group cannot move forward."

While they initially clearly distinguish between the defined capabilities, Dennis and Valacich base most of their propositions on what they call "media synchronicity". Media synchronicity is an aggregated measure positively influenced by feedback capability and negatively influenced by parallelism: processes focussed on convergence favour media providing high synchronicity, processes focussed on conveyance are best supported by media providing low synchronicity, established groups require less media with high synchronicity, newly created groups require more media with high synchronicity, and as a group develops over time it will require less media with high synchronicity. The remaining capabilities, symbol variety,

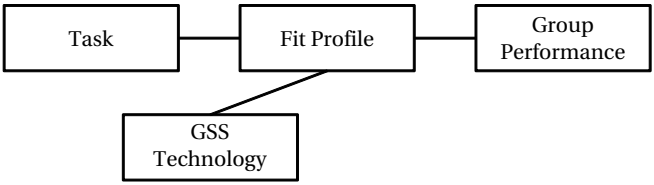

Figure 2.9: General model of task technology fit [ZB98]

rehearsability, and reprocessability offer only very general propositions: symbol variety only affects performance if a set is not given, higher rehearsability leads to better performance, conveyance processes require media with higher reprocessability, and newly created groups are best supported by media providing a symbol set of high social presence.

2.2.6 Task-Technology Fit Theory

Zigurs analyses the complex of communication media selection from the perspective of tasks [ZB98; ZK08]. The central question to her work is, "Can we specify particular combinations of task and Group Support System (GSS) technology that will enhance group performance?" She provides definitions and categorisations for task, fit and technology and derives a model of how the former two influence the latter (see Figure 2.9).

Zigurs defines a task as "the behaviour requirements for accomplishing stated goals, via some process, using given information." Her categorisation scheme for tasks revolves around the four dimensions outcome multiplicity, solution scheme multiplicity, conflicting interdependence, and solution scheme/outcome uncertainty. Outcome multiplicity does not refer to the number of viable solutions, but to

	Comm. Support	Process Structuring	Information Processing
Simple Task	High	Low	Low
Problem Task	Low	Low	High
Decision Task	Low	High	High
Judgement Task	High	Low	High
FuzzyTask	High	Medium	High

Table 2.3: Fit profiles of task categories and technology dimensions

the number of criteria involved in evaluating a task. An example task would be the selection of a new car based on multiple criteria like fuel economy, comfort, number of passengers, and trunk space. The dimensions solution scheme multiplicity covers the possibility of multiple "solution paths" being available to reach the same task outcome. Conflicting interdependences occur when possible solution schemes, outcomes, or information are mutually exclusive. Lastly, with a high solution scheme or outcome uncertainty, one cannot be sure, whether a chosen solution scheme will lead to the desired outcome. Based on these four dimensions, Zigurs aggregates tasks into five categories: simple task, problem task, decision task, judgement task, and fuzzy task (see Table 2.3).

Similar to the dimensions Zigurs introduced for tasks, she differentiates GSS technologies based on the three aspects communication support, process structuring, and information processing. Communication support enables group members to communicate with each other and combines aspects such as simultaneous input, anonymous input, feedback, and group display. Process structuring supports, enhances, and defines the interaction processes of a group for example, by setting or enforcing the agenda, by facilitation, or by recording the

group interaction. Lastly, information processing enables the group members to collect, share, aggregate, structure, or evaluate information.

Zigurs defines fit in the context of task and technology as an ideal profile (see Table 2.3) composed of task properties and technology characteristics, which influence group performance. Strong conformance to the ideal profile leads to better group performance.

2.2.7 Web 2.0 and Enterprise 2.0

As many of the recent communication media are considered "Web 2.0" technology, it is helpful to understand the origins of this term and its implications. The following paragraphs will thus introduce the basic concepts of Web 2.0 and the related term Enterprise 2.0.

In 2006, Andrew McAfee coined the term "Enterprise 2.0" borrowing from "Web 2.0", which emerged almost two years earlier [McA06; ORe05]. The expression Web 2.0 was born after the collapse of the dot-com bubble in 2001 at a conference brainstorming session, which led to the accordingly named conference series from 2004. Even though the initial definition of the new term was by comparing Web 1.0 services like Britannica Online to Web 2.0 services like Wikipedia, and O'Reilly stated, "Web 2.0 doesn't have a hard boundary, but rather, a gravitational core", he provided seven principles, which are essential to the concept of Web 2.0 [ORe05]:

The Web as Platform: Applications provided via the web are delivered as a service and are not packaged. No complex sale of licenses hinders the adoption. The essential element of these applications is the data, which is automatically managed by algorithms, for example, product rankings based on popularity and ratings. This automation

enables the applications to reach the long tail of the web with fewer sales of more niche products [And06; BHS06].

Harnessing Collective Intelligence: As users create content on their personal websites, blogs, or public wikis, others discover the new information and link to it via permalinks or trackbacks. Based on this collective activity, the "blogoshpere" grows organically, resembling the structure of synapses in the brain. Similarly, commercial web platforms such as Amazon or eBay, provide their users with the context in which they can author product reviews or rate each other after a trade. Another example of collective intelligence is folksonomies, wordplay on the traditional top-down taxonomies for categorisation. Sites such as Flickr allow their users to tag content with keywords. These keywords are then assembled into bottom-up categorisations based on co-occurrence and co-use [GH06; Jäs+07].

Data is the Next Intel Inside: At the core of many applications provided via the web, are vast databases such as Amazon's product and review database, eBay's database on sellers and buyers or Google's map database. Owning instead of licensing essential data can prove existential for a business, as others could license the same data and provide competing services. Another phenomenon of the Web 2.0 is so called mashups. Mashups link together multiple data sources in order to provide value-added services like housing prices as a map overlay [Yu+08]. On the downside of this emerging data business are concerns about ownership of personal data and the associated privacy.

End of the Software Release Cycle: As applications are provided as a service instead of a product, their operation becomes a core competency. A Web 2.0 application "will cease to perform unless it is

maintained on a daily basis." Users become co-developers, as their behaviour is analysed in real-time. As a result of shorter release cycles, phrases like "release early release often" or "perpetual beta" have emerged.

Lightweight Programming Models: Soon after the idea of web services surfaced, complex programming environments for distributed applications like Simple Object Access Protocol (SOAP) emerged and found their niches. On the Web 2.0 though, simple and pragmatic solutions such as Representational State Transfer (REST) prevailed [PZL08]. The lessons are that successful Web 2.0 implementations support lightweight programming of loosely coupled systems and favour syndication over coordination.

Software Above the Level of a Single Device: This principle refers to the fact, that many Web 2.0 applications not only span multiple servers and personal computer, but work across various types of devices. For example, iTunes from Apple seamlessly integrates its servers with a personal computer and multiple mobile devices like the iPod. O'Reilly asks prophetically, "What applications become possible when our phones and our cars are not consuming data but reporting it?"

Rich User Experiences: Early on in the development of the web, concepts of richer interaction with web content arose, but the then raging browser war between Microsoft and Netscape held them back. Only after this conflict was decided, the Asynchronous Javascript and XML (AJAX) framework achieved new levels of interactivity. New web applications like Gmail or Google Maps achieved personal computer like richness and usability. Google Docs offers a Web 2.0 based word processor and spreadsheet-calculator, which can be collaboratively

used in wiki-style.

While the term Web 2.0 is targeted at any application, following the principles mentioned above, McAfee distinguishes Enterprise 2.0 as the specific application in companies: “I use the term Enterprise 2.0 to focus only on those platforms that companies can buy or build in order to make visible the practices and outputs of their knowledge workers”[McA06]. Following a similar structure as O’Reilly, he distinguishes six components of the Enterprise 2.0 concept leading to the acronym SLATES: search, links, authoring, tags, extensions, and signals.

Search: He discriminates between two approaches to make content easy to find, a centralised structure maintained by professional staff and the Google-like distributed search based on the structure on the links between content. In a survey regarding intranet usage, “less than half of respondents reported that it was easy for them to find what they were looking for” while “87% of Internet searchers report having successful search experiences”. The latter type of search already implies the next Enterprise 2.0 component:

Links: A dense and dynamic structure of links between content is essential for Google-like search algorithms, in order to derive a ranking based on the link frequency. In a traditional, hierarchical company intranet, a small group defines the link structure, which thus just reflects their perspective. In order to achieve an internet-like linkage, all involved users need to be able to link to content, which they deem important.

Authoring: Cunningham, the developer of the first wiki, made the point, that almost everyone has something to contribute, be it knowledge, insight, experience, a comment, a fact or a link [EG05]. Follow-

ing this approach, many Web 2.0 related tools enable the user to author content in a straightforward manner without intermediate editors. The content provided in this way, forms the basis for the link structure and dynamic search algorithms.

Tags: Similar to the distinction between centralised and distributed search, McAfee identifies two means to categorise content: taxonomies and folksonomies. A taxonomy is a hierarchical classification scheme usually developed by a few experts. By comparison a folksonomy is an emergent classification scheme that is based on the keywords many users apply in order to classify objects.

Extensions: Extensions take statistical data collected from many users into account and offer logical extensions to the users' behaviour. If user A buys product X and many other users who bought product X also bought product Y, it is likely that user A might as well be interested in product Y.

Signals: Signals refer to technologies like the aforementioned Really Simple Syndication (RSS) or email alerts, which update a user, whenever new content becomes available. By employing such tools, users can avoid constantly re-checking content sources even if there is no new content available.

These six principles provide a framework for the analysis and design of corporate communication. Together they distinguish social '2.0' media from what one might call traditional '1.0' media. McAfee provides practical insight based on case studies on how this framework can be applied in businesses and how they change structures and processes [McA09]. One of his conclusions is that "the technologies of Web 2.0 and Enterprise 2.0 have the wonderful property of causing patterns and structure to appear over time".

2.2.8 Communication Media

With the plethora of currently available means to communicate, only the media relevant in the context of this dissertation will be introduced in the following paragraphs.

Face-to-Face: Although there is currently no agreement on the exact time when human language developed and some even consider this "the Hardest Problem in Science" [CK03], it is clear that gestures and speech were the earliest forms of human communication. In principle, the estimates range from 2.4 million years ago to just 50,000 years ago [Fis01]. When two persons communicate face-to-face, many of our senses are activated. They judge the pressure of a handshake, sense the others odour or perfume, perceive gestures or facial expressions, and exchange ideas via spoken language.

Group Meeting: A group meeting is mostly identical to the face-to-face dialogue. The difference is that it involves more than two participants with the maximum number usually limited by factors like room size and acoustics [GL91; RN01]. In a usual group meeting, many persons interact simultaneously with the role of speaker being switched from one to another in order to avoid disorder. Nonetheless, multiple parallel conversations can occur from time to time.

Presentation: A presentation differs from a meeting, in that only one speaker is providing information, while the audience is listening.

Telephone: Face-to-face and its derived communication styles are limited by the reach of the human voice. Although there is some controversy whether Phillip Reis, Elisha Gray, or Alexander Graham Bell invented the telephone only the latter can be considered the winner of this dispute. Bell received the patent for his invention in 1876 and established the "Bell Telephone Company" which

later evolved into the "American Telephone and Telegraph Company" (AT&T) [Rob06]. While the early telephone systems relied on manual switching of the wires, today's systems automate this process and each participant can be reached via his unique phone-number. Even people without much technical knowledge can now have a voice conversation spanning around the globe.

The first hand-held mobile phone was developed by Martin Cooper and his team at Motorola in 1973. Their race for the technology with Bell Labs ended on April 3, 1973, when Cooper used the first prototype to call Joel S. Engel of Bell Labs [Coo+76]. In the past decade, the mobile phone evolved into what is now called a "smartphone". It is now a small mobile computer integrating traditional telephone capabilities with additional functions like calendar, address-book, multi-media playback, photo and video camera, car navigation, web browsing, and many more. Because most current smartphone systems offer programming interfaces, additional third-party programs, so called "apps", can extend their functionality [CL11]. According to a survey by the "Pew Internet & American Life Project", smartphone users outnumbered the users of traditional mobile phones in the United States in early 2012 [Smi12].

Telephone Conference: Most current telephone systems support more than two parties in the same call, which is then called a telephone conference. Because of the limiting single audio channel, telephone conferences do not support multiple parallel conversations in one conference.

Video Conference: Early video telephone systems already emerged in the 1930ies, when the German Post started to use the "Television-Telephone" system connecting Berlin and several Ger-

man cities [Ass34]. Since then, technology has improved dramatically with prices dropping at the same time. Today, every common computer or even a smartphone are able to hold a high-definition video conference [OBL09].

Short Message Service (SMS): Similar to older systems like Telex, the short message service allows the users of mobile phones to exchange brief text messages between each other. It is part of the Global System for Mobile Communications (GSM) standard and was developed during the late 1980ies and broadly deployed in the early 1990ies. Because of protocol specifications, its maximum size is restricted to 140 bytes. A message can contain up to 160 characters by using a reduced alphabet of 7 bit per character [Hil+10].

Letter: Written language first emerged around 3200 BCE in Mesopotamia and enabled our ancestors to record spoken language permanently [Fis01]. Today's mail is commonly written or printed on paper and is protected by a sealed envelope. Courier or mail services transport the mail from sender to receiver, which accounts for the comparably long transmission time of this form of communication.

Fax: A fax machine converts a physical original document into an electronic representation, which can be transmitted across vast distances at almost the speed of light. The receiving machine on the other end then converts the electrical signals back to human readable form. The Scottish inventor Alexander Bain conceived the first such system and received the according patent in 1843. The first commercial fax-service started operating in 1865 [Kar09]. The high times of the fax system were in the 1980ies and -90ies [Hil+10].

Email: Email as we know it today, a system able to transmit electronic text messages between users across multiple networked

servers, emerged in 1971 when Raymond Tomlinson implemented the first networking capable version of SNDMSG, an early mail program. In need for a way to distinguish local messages from networked ones, he chose the @-sign to separate the user name from the name of the target server. On his own website he says about the first email messages, that they "were entirely forgettable and I have, therefore, forgotten them " [Tom12]. The importance of email in engineering communication is highlighted by the empirical findings of the TRUST project: About 90% of the information exchanges are done by email [VAK13].

Today, the request for comments [Int08a] by the Internet Engineering Task Force specifies the formal format of an email and the "Multipurpose Internet Mail Extensions" define the multi-media content attachments. The sending, transmission, and retrieval of emails currently relies on the protocols "Simple Mail Transfer Protocol" [Int08b], "Post Office Protocol" [Int96], and "Internet Message Access Protocol" [Int03].

Email Newsletter: While the sender of a normal email needs to specify all recipients individually, a newsletter is automatically addressed to a large group of interested users. The users can usually register and de-register themselves in an automated way via email messages or web interfaces. Only a few users are able to send messages via a newsletter and a direct reply is either not expected or often even not possible.

Email Mailinglist: In contrast to the limited sender group of newsletters, a mailinglist is open to most or all registered users. The system forwards whatever message any user sends to the mailinglist to all other registered users. Direct replies via the list itself

are expected and encouraged and add to the discursive nature of this medium.

Blog: The term *blog* is an abbreviation of the term *weblog* and emerged in 1999 after Peter Merholz started pronouncing "weblog" as "we-blog" in early 1999 [Her+04]. The author of a blog usually publishes articles or commentaries in a chronological manner. Blogs are often categorised by their focus (personal or corporate), their genre (e.g. travel blog), or their media type (e.g. photo blog).

A distinct sub-type is a micro-blog, which limits the content of an individual entry to a certain amount (140 characters in the case of Twitter).

Wiki: "A wiki is a website which allows its users to add, modify, or delete its content via a web browser usually using a simplified mark-up language or a rich-text editor." This quote is taken from Wikipedia, a wiki-based encyclopaedia in itself. Wikipedia uses the wiki approach to provide a collaboratively edited encyclopaedia online. Ward Cunningham developed the first wiki, "WikiWikiWeb", and named it after the Hawaiian word for fast or quick [Wik12; EG05; Hir+12].

As many wikis have a very low level of access control, they put stronger emphasis on traceability. Wikipedia, for example, records every change ever made to an entry together with the internet address from which the entry was edited. It is thus simply possible to revert to the previous state if a malicious change occurs.

Collaborative Writing: Although synchronous collaborative writing has been available before, it became commonplace with web based services such as Google Docs or Etherpad [Cal+11]. Especially the former provides editing capabilities for all common types of office

documents: text, tables, and presentations. Multiple users can synchronously edit the same document with all changes directly highlighted to all participants.

Decision Support: Web based Decision Support Systems (DSSs) like Doodle or the privacy enhanced Dudle greatly simplify collaborative event scheduling or decision making. In both systems, the initiator provides a range of potential dates or decision options and sends the resulting link to the other participants. Each one can then provide feedback with the current results being directly visible to all involved. [KB09]

Shared Drive: Most major operating systems include protocols in order to access files via network. In 1984, Sun Microsystems developed the Network File System (NFS) for the UNIX world. Apple included early versions of the Apple Filing Protocol (AFP) with Mac OS System 6 in 1988. Microsoft extended the Server Message Block (SMB) originally developed by IBM and included it in Windows for Workgroups in 1992. Users can access shared drives attached through these or similar protocols like any usual local hard-drive. Issues often arise, when multiple users write to the same resource at the same time, as the common protocols do not implement locking mechanisms.

Intranet 1.0: The first intranets in the early 1990ies resembled private versions of the World Wide Web (WWW) and were only accessible from within a company. They relied on the Transmission Control Protocol / Internet Protocol (TCP/IP) for distribution and on the Hypertext Mark-Up Language (HTML) to store and present the content [McC96]. In order to preserve order and usability, these intranets were commonly organised in a hierarchical fashion, with administra-

tors mediating additions and updates.

Document Management: Document Management Systems (DMSs) are used to store and organise electronic documents. The documents are versioned, enriched with meta-data and are often full-text indexed in order to simplify search and retrieval. Integration of workflow engines enables the automation of common processes involving documents like release processes or change proposals. Being file based, DMS do not support the synchronous editing of the same document by multiple users [Dou+00].

2.3 Business Process Modelling

BPM derives from Systems Engineering and describes the activities needed to analyse and improve the processes of a business. Harold Chestnut and Stanley Williams coined the term in their work "Business process modeling improves administrative control" [CW67]. In order to facilitate the human interpretation and interaction with the created models, a large number of graphical standards and de-facto standards has emerged over the years: The Gantt Chart, named after its inventor Henry Laurence Gantt, emerged early in the twentieth century [Gan10], the Flow Chart was devised by Frank Bunker Gilbreth, a member of The American Society of Mechanical Engineers, in 1921 [GG21], and the Integration Definition (IDEF) family of diagrams emerged from the U.S. Air Force Program for Integrated Computer Aided Manufacturing (CAM) during the 1970s [Nat93]. The latter formally specified different models for different applications. Among others IDEF0 for functional models, IDEF1 for information models, and IDEF2 for dynamics models.

Depth/Breadth	**Understanding & communicating**	**Process improvement**	**Process management**	**Process development**	**Process execution**
Informational (data)	(Flowchart) (IDEF3) DFD ERM State transition IDEF1x UML	(Simulation) DFD ERM State transition IDEF1x UML	Simulation DFD ERM State transition IDEF1x UML	Simulation DFD ERM State transition IDEF1x UML	Simulation DFD ERM State transition IDEF1x UML
Organizational (where, who)	(IDEFO) (Simulation) System dynamics RAD	(IDEFO) Simulation System dynamics RAD	(IDEFO) Simulation System dynamics RAD	Simulation (UML) (RAD)	-
Behavioral (when, how)	(IDEF3) Simulation System dynamics RAD	(IDEF3) Simulation System dynamics RAD	(IDEF3) Simulation System dynamics RAD	Petri nets Simulation System dynamics Knowledge based (State transition)	Petri nets Simulation Knowledge based (State transition)
Functional (what)	Flowchart IDEF0 (IDEF3) Simulation (System dynamic) DFD (UML)	Flowchart IDEF0 (IDEF3) Simulation System dynamics DFD (UML)	Flowchart IDEF0 (IDEF3) Simulation	IDEF0 Petri nets Simulation DFD UML	Petri nets Simulation DFD UML

Table 2.4: A taxonomy of BPM/ISM techniques [Gia01]

	Type	Background	Focus	Standardised	Current status
BPDM	BPM	Industry	Interchange	Yes	Unfinished
EPEL	BPM	Industry	Execution	Yes	Popular
BPML	BPM	Industry	Execution	Yes	Obsolete
BPQL	BPM	Industry	Diagnosis	Yes	Unfinished
BPRI	BPM	Industry	Diagnosis	Yes	Unfinished
ebXML BPSS	B2B	Industry	B2B info exchange	Yes	Popular
EDI	B2B	Industry	B2B info exchange	Yes	Stable
EPC	BPM	Academic	Graphical	No	Legacy
Petri Net	All	Academic	Theory/graphical	NA	Popular
Pi-Calculus	All	Academic	Theory/execution	NA	Popular
Rosetta-Net	B2B	Industry	B2B info exchange	Yes	Popular
UBL	B2B	Industry	B2B info exchange	Yes	Stable
UMLAD	BPM	Industry	Graphical	Yes	Popular
WSCI	SOA	Industry	Execution	Yes	Obsolete
WSCL	SOA	Industry	Execution	Yes	Obsolete
WS-CDL	SOA	Industry	Execution	Yes	Popular
WSFL	BPM	Industry	Execution	No	Obsolete
XLANG	BPM	Industry	Execution	No	Obsolete
XPDL	BPM	Industry	Execution/interchange	Yes	Stable
YAWL	BPM	Academic	Graphical/execution	No	Stable

Table 2.5: Status of prominent BPM standards, languages, notations, and theories [KLL09]

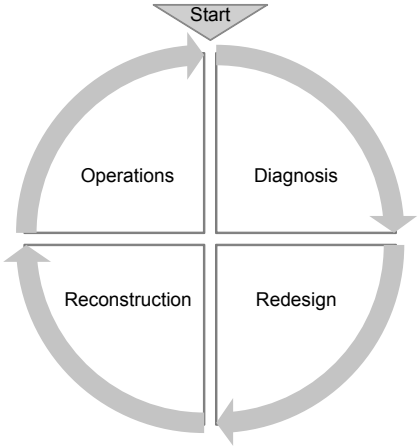

Figure 2.10: BPR lifecycle [AH04]

Three more contemporary standards for handling business process models are the Unified Modeling Language (UML) activity diagram [Obj05a; Obj05b] and the Business Process Model and Notation (BPMN) [Obj10; Obj11] that are both specified by the Object Management Group (OMG) as well as Event-driven Process Chains (EPCs) which emerged in 1992 from a research project involving the Institute for Information Systems of the University of Saarland and SAP AG [STA05]. Section 2.3.1 and Section 2.3.2 will explain the latter two in more detail.

As the modelling techniques mentioned above represent only a small fraction of the present BPM landscape, tools for the structuration of this field emerged. Giaglis devised a two dimensional taxonomy classifying BPM approaches along the axes “process perspective” and “goals and objectives” [Gia01]. The perspective axis differentiates between the four categories functional, behavioural, organisational, and informational perspective while the objectives axis is

comprised of the five categories understanding and communication, process improvement, process management, process development, process execution (see Table 2.4).

Van der Aalst and van Hee propose a concept very similar to the "goals and objectives" axis introduced by Giaglis, the "BPM lifecycle" [AH04]. It consists of four life phases: "diagnosis", "redesign", "reconstruction", and "operations" (see Figure 2.10). In the first phase, one analyses the current situation and the problems specific to the way the processes currently operate. Based on the findings one defines objectives which can later on be used to measure the improvements. During the second phase, a new design is developed based on previous findings. In the following third phase, the IT-systems and organisational structure are realigned to the new process design. Finally, in the fourth phase, the new processes are actually performed and their performance is assessed based on the objectives defined in the first phase.

Ko et al. provide another helpful clarification of the BPM landscape in their paper "Business process management (BPM) standards: a survey" [KLL09]. In addition to the concepts introduced above, they offer further classification criteria for BPM standards: "graphical standards" which enable the user to express business processes in a diagrammatic way, "execution standards" which computerise the deployment and automation of business processes, "interchange standards" supporting portability of data across systems, and "diagnosis standards" for administrative and monitoring purposes. Table 2.5 shows their classification of various BPM related standards.

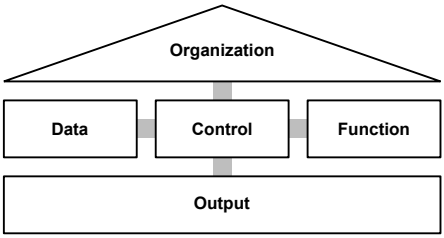

Figure 2.11: ARIS house view of a business process [STA05]

2.3.1 Event-Driven Process Chain

In 1992 SAP AG and the Institute for Information Systems of the University of Saarland conducted a research project during which the EPC approach was developed. Subsequently this became a key component of SAP R/3 and the modelling notation supported by the Architecture of Integrated Information Systems (ARIS) tool set [Sch99a; Sch99b]. ARIS structures the high complexity of BPM with two approaches: a view concept and the definition of life cycle phases. The different perspectives, namely organisational view, data view, control view, function view, and output view, and their relationships are visualised in the ARIS House as seen in Figure 2.11. The three life cycle phases “Requirements Definition”, “Design Specification”, and “Implementation Description” subdivide each view. Deviating from the usual life cycle concepts, ARIS does not follow a procedural model but rather defines the different phases according to their proximity to information technology.

The EPC represents business processes as a continuous sequence of enterprise activities delivering a purposeful output. The specification of the elements used to define an EPC evolved in two phases.

The initial version defined three core categories of elements:

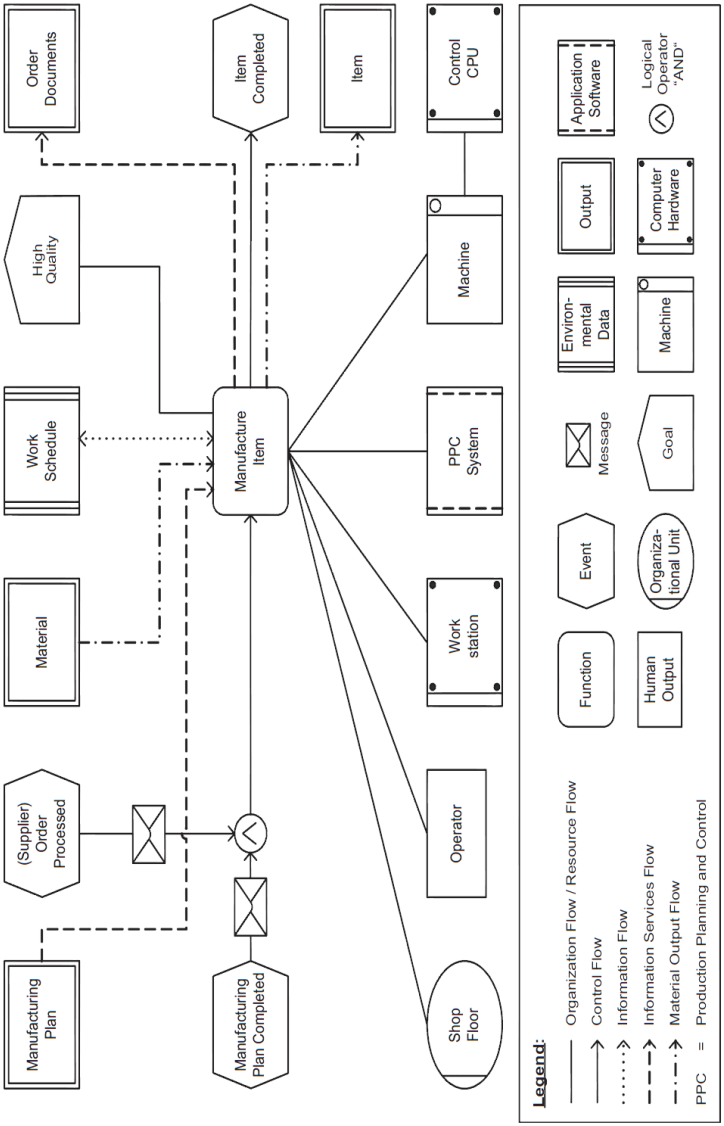

Figure 2.12: Detailed excerpt of the business process "order processing" [STA05]

events, functions, and control flows [STA05]. Events are the preconditions for functions and can be the result of functions. They are not associated to costs or time consumption, but can define a probability of their occurrence. Functions represent activities or processes and are activated by events. Costs and time consumption can be associated to functions. Control flows define the sequence between events and functions and can also represent logical dependencies: "exclusive or" states that only one case can be true at a time, "or" states that one or more cases can be true at the same time, while "and" states that all cases must be true at the same time.

The subsequently developed Extended Event-driven Process Chain (eEPC) adds elements representing organisational units and information elements and their respective flows: organisational units, messages, goals, environment data, machines, outputs, hardware, and software. Figure 2.12 shows a summary of all eEPC elements. These additional elements represent the different views defined by the previously described ARIS house.

2.3.2 Business Process Model and Notation

In 2000, the Business Process Management Initiative was established as a consortium with the intention to promote the development of business process modelling. The initiative developed the Business Process Modeling Language and the Business Process Query Language. As an addition to their modelling language, they also developed a graphical notation, the Business Process Modeling Notation, note the missing "and". After the merger with the OMG in 2005, the notation was renamed to Business Process Model and Notation (BPMN) to highlight its abilities to serve also as a model based on

the EXtensible Markup Language (XML). While the initial releases 1.0, 1.1, and 1.2 focussed on the originally intended graphical notation, the current release 2.0 comprises model, notation, and a standardised XML schema enabling the exchange of BPMN models [Ear11; Obj11].

Opposed to the previously discussed EPC, the scope of BPMN is strictly limited to business processes, explicitly excluding organisational models, data or information models, strategy models, functional breakdowns, and business rules. Following this focus, a BPMN model can contain three types of sub-models: Processes, Choreographies, and Collaborations. Processes can be either private or public. Private processes are internal to a single organisational structure, while public processes show the interaction between a private process and another process or participant. In a public process, the activities of the private process remain hidden and only those activities related to the communication between the private and the public process are shown. A public process thus highlights the outside world message flows of a private process. Choreographies are similar to private processes, in that they appear as a sequence of activities. The difference is that such an activity represents a set of message exchanges between two or more participants. Collaborations depict the message flows between two public processes, highlighting the touch-points between the participants. A specialised variant of a collaboration diagram is the conversation diagram, which captures the message exchanges between participants, leaving out all other process information. A single conversation collects multiple message exchanges concerning the same business object [Obj11]. Because of its relevance to this thesis, the conversation diagram will be explained

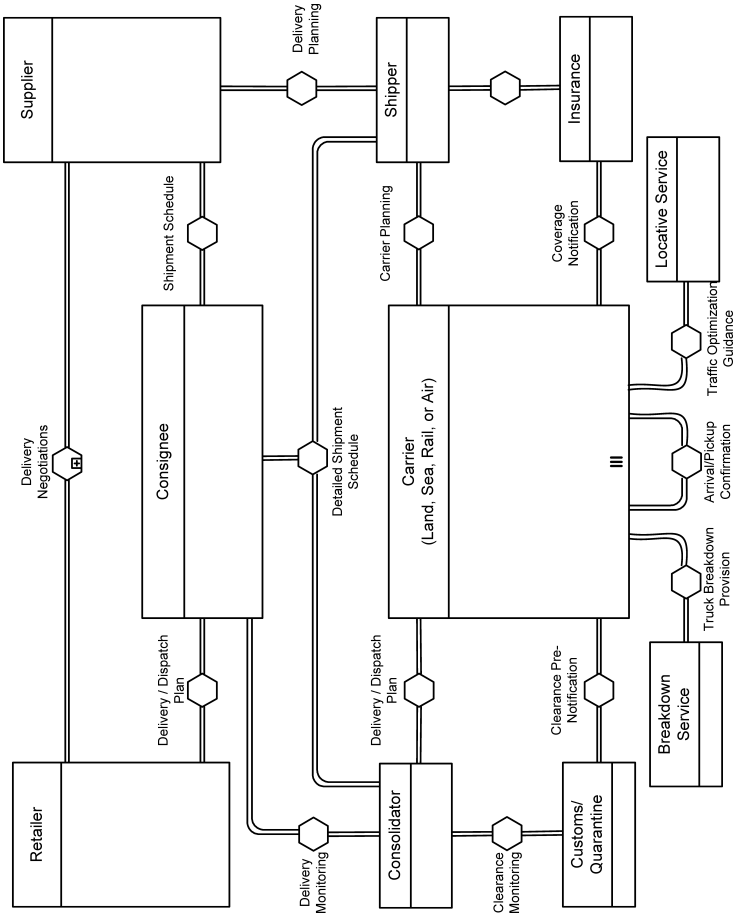

Figure 2.13: An example of a conversation diagram [Obj11]

in more detail.

The conversation diagram is derived from the aforementioned collaboration diagram. It is similar in that it depicts the communication between participants, but it differs in that it does this on a more abstract level. Instead of explicitly detailing every single exchanged message, one Conversation groups multiple messages together. By doing so, a conversation diagram provides a clear overview of the communication between multiple participants. Figure 2.13 shows an exemplary conversation diagram with its typical elements: participants, conversations, and conversation links. As each conversation correlates to the involved messages, it is possible to detail the conversation in an additional choreography or collaboration diagram.

2.3.3 Communication Orientation in BPM

In 1996, Kock and McQueen conducted a study regarding the nature of business processes. An essential outcome of this study is that even in manufacturing companies about 80% of the flows in business processes are information oriented and only about 20% account for materials [KM96]. In the light of their results, Kock et al. went on to analyse the impact of different business process representations on the outcome of business process re-engineering. Many common representations of business processes focus on workflows, the chronological order of activities in a process. This makes sense in a process which transforms materials and leads to a physical product but is inconsistent with the information rich processes common today [Koc03; KDK08; Koc+09].

Figure 2.14 shows their classification of various representations of business processes. According to their work, flowcharts form the

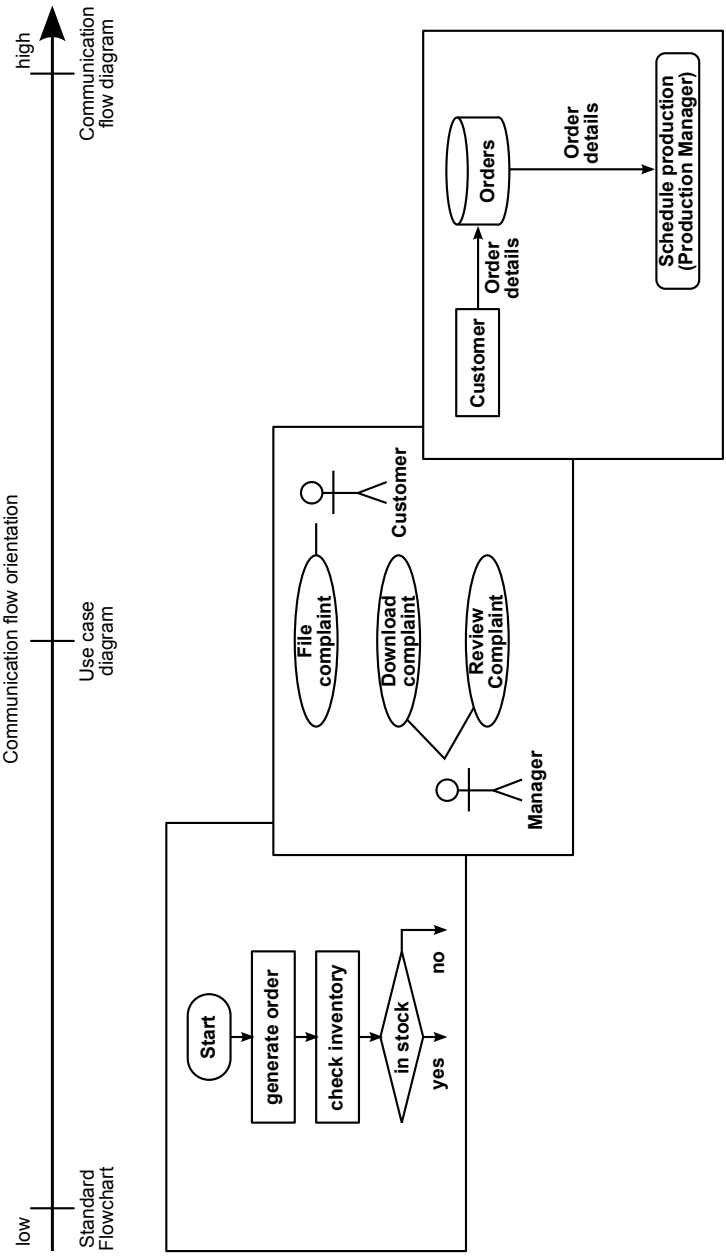

Figure 2.14: Communication flow orientation of different business process diagrams [Koc+09]

lower end of the communication flow orientation spectrum. Activity diagrams and use case diagrams provide a more comprehensive view of communication flows and communication flow diagrams constituted the upper end of the spectrum.

Based on a number of empirical studies, Kock et al. concluded that the communication flow orientation of the business process representation used in a business process re-engineering operation has a substantial impact on the outcome [Koc+09]. In general their findings showed that "the degree of communication flow orientation of a business process model was found to be significantly and positively related to the perceived ease of generation, ease of understanding, and accuracy of the model", which in turn are "significantly and positively related to the degree of business process redesign success".

2.4 Collaborative Research Center 666

As the case study presented in Chapter 5 is conducted within the Collaborative Research Center 666, this section will provide a brief overview of its aims and structure. It will also introduce a previous work in this context, which examined the communication processes within the research centre.

2.4.1 Organisation of the Research Center

The German Research Foundation (DFG) and the Techische Universität Darmstadt founded the CRC 666 in 2005 in order to research the possibilities of new production processes for sheet metals. In addition to the production of integral sheet metals, the research centre also integrates the development, evaluation, and synthesis of new

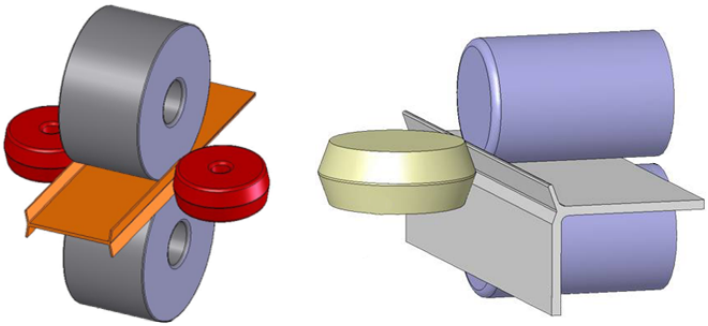

Figure 2.15: Linear flow splitting [Gro+09] and linear bend splitting [RG08]

product based on the new technology. To support this approach, methods from the domains of mathematics, mechanical engineering, civil engineering, and material science need to be applied [GS10].

The core of the research centre is a new method of manufacturing bifurcated sheet metal. Other than traditional differential design approaches, this new method allows the manufacturing of sheet metal with higher order bifurcations as an integral part. The researchers applied the general method to two approaches, linear flow splitting, and linear bend splitting. The former creates a bifurcation at the edge of the sheet metal, while the latter bifurcates the sheet metal on the surface. In order to create a split on the surface traditional bending creates a new edge. The process of linear flow splitting is then applied to this edge and the sheet metal is bent back into its desired shape. Figure 2.15 shows basic illustrations of both processes.

Following the structure of the involved life cycle processes, the CRC 666 is organised in four major divisions: Product Development (A), Production (B), Evaluation (C), and Synthesis (D). Each division is again split into sub-projects:

Product Development

- Requirements and properties (A1)
- Geometry optimisation (A2)
- Geometric modelling (A4)
- Information model (A5)
- Optimisation for deep drawing (A6)

Production

- Linear flow splitting (B1)
- Cutting processes (B3)
- Manufacturing of bifurcated parts (B4)
- Deep drawing of bifurcated structures (B5)
- Surface layer modification (B6)

Evaluation

- Mechanical properties (C1)
- Fatigue behaviour (C2)
- Component optimisation (C3)

Synthesis

- Bearing systems (D1)
- Surface structures (D2)

In product development, the first sub-project provides the requirements and properties, which are used by the optimisation and modelling sub-projects. Together with customised optimisation processes and newly implemented geometry features in Computer Aided Design (CAD), they provide an integrated geometric model of the final product [Rol+11; SWA11]. The information model created in subproject A5 portraits the availability and distribution of the various types of information created throughout the research centre [And+07; Wei+12].

The production division of the research centre further develops the two manufacturing processes for linear flow splitting and linear bend splitting. The improved processes will enable the splitting along a non-linear edge of sheet metal as well as the deep drawing of sheet metals that have been bifurcated on their surface. These processes will also monitor their essential dimensions and parameters in-line.

Current results of the evaluation show that traditional approaches cannot model the "ultra-fine-grained" microstructure that the transformed bifurcation zone of the sheet metal develops. Thus, the target of this sub-project is to develop new mathematical methods and material models that allow the design of new products while considering relevant safety margins.

The findings of previous research in the centre identified two promising concepts: Linear bearing systems and surface structures with integral stiffeners. The aim of the synthesis division is to develop these concepts into products by integrating the results from the domains product development, production, and evaluation in order to highlight the advantages of the new technology.

In order to facilitate the exchange across the different domains, work groups focussing on the products mentioned above include sub-projects from multiple divisions.

2.4.2 Previous Work on Communication

As part of his diploma studies, Ewgenij Feicha wrote a thesis analysing the information flows at the CRC 666 in order to apply the simultaneous engineering approach to the research centre [Fei12]. He applied the established methods and models of business process modelling (see Section 2.3) in order to identify the inputs, outputs,

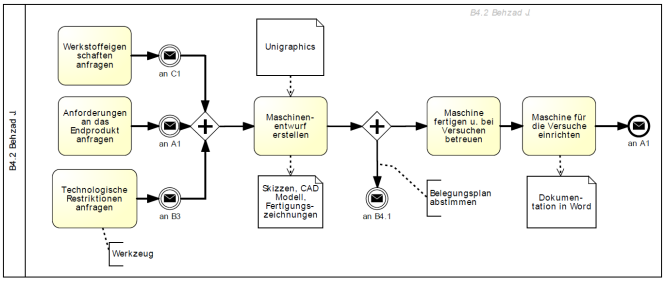

Figure 2.16: BPMN process diagram of an individual sub-project [Fei12]

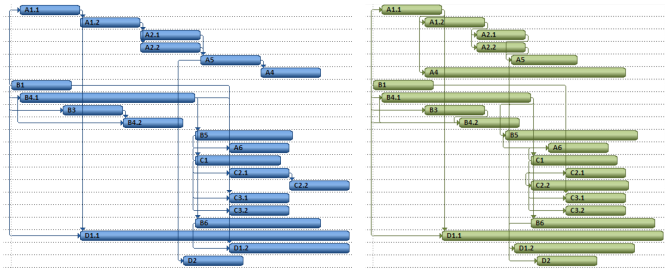

Figure 2.17: Gantt diagram of unoptimised and optimised processes [Fei12]

and interfaces between the different sub-projects. As a result, he provided comprehensive BPMN process models of all sub-projects, which he derived from a series of interviews with the involved scientists (see Figure 2.16). Feicha analysed the individual processes of the sub-projects and distinguished between core and auxiliary activities. He found that many work packages start with auxiliary tasks like general preparation or gathering of necessary information. By parallelising these activities with core activities of other dependent projects, he proposed an optimised schedule of work packages as shown in Figure 2.17.

2.5 Conclusion

As was shown in the first section of this chapter, the contemporary methods of product development, namely product life-cycle management, simultaneous engineering, concurrent design, and agile approaches greatly increase the volume of communication compared to sequential approaches.

Lacking clear guidelines regarding what communication medium to apply in which context, making all potential communication media available in parallel, may be tempting for many planners in businesses. The issue here is that according to critical mass theory, the resulting dispersion of users across many possible communication media would hinder general acceptance. The thinned-out user base in each individual medium would be below a certain threshold, resulting in too few potential communication partners to achieve universal access.

In order to find guidance, the following section examined media selection theories, which introduce novel measures characterising communication media like media richness, media synchronicity, or task-technology fit. While the individual characteristics such as immediacy of feedback, the used language, parallelism, or synchronicity are quantifiable, the aggregated measures remain only qualitative. By applying the characteristics individually on an atomic level, clearer conclusions could be derived. Moreover, the characteristics proposed by the individual theories are not sufficient to differentiate clearly between the many new computer mediated communication media developed in the recent decades.

Kock et al. show that the communication flow orientation of the business process representation used in a business process re-

engineering operation has a positive impact on the outcome. But still the diagrams provided by current modelling standards such as UML, EPC, or BPMN only capture a bare minimum of information relevant to communication, namely who is communication with whom about what.

In summary, what is lacking is a communication oriented business process model that also integrates the characteristics provided by communication theory. Such a model would support the detailed analysis, understanding, and planning of communication intensive business processes in product development.

Chapter 3

Requirements

"If the right product is to be built, the right requirements have to be discovered."

In order to identify the right requirements the systematic approach defined by Robertson and Robertson will be explained and applied in the following paragraphs [RR12]. The process first clarifies the goals and the scope of the project and identifies the involved stakeholders. It then establishes use cases and scenarios that make the problem at hand more accessible. It specifies the requirements based on the scope, the stakeholders, the use cases, and the scenarios. Following this structured approach increases the likelihood of discovering all relevant requirements.

The goal of the project provides a clear statement about the purpose, i.e. the intended outcome and the benefits of the project. In a way, it resembles the highest-level overall requirement. The specification of the project goals also includes a brief summary of the background and an assessable description of the intended results.

Scoping the project includes drawing a boundary specifying which functionality should be included and which elements are outside the scope. The stakeholders include all persons who have an interest in the project, who can provide helpful knowledge, and whose decisions impact the outcome.

The use cases present the typical interactions between the stakeholders and the to-be-defined solution. A standardised solution to specify these interactions are Use Case Diagrams as provided by the Unified Modeling Language. The scenarios extend this information by providing systematic explanations of what activities occur in each use case. The scenarios are written in commonly understandable language and thus ease the interaction of various stakeholders.

The requirements finally distil all the collected information into simple, understandable, and testable packages. Each requirement contains a brief description, the rationale, and a fit criterion that quantifies or measures the requirement and thus makes it testable. The requirements can be classified into functional and non-functional requirements. The functional requirements describe *what* the solution does and the non-functional requirements describe *how well* it does what it does [RR12]. Although the unintuitive naming might imply otherwise, neither type of requirement should be neglected.

3.1 Overall Goal

Even though the contemporary business process modelling approaches described in Section 2.3 include models and diagrams focussing on communication processes, they do not capture all the in-

formation relevant to a proper examination of the communication requirements. For a comprehensive analysis and planning of communication processes and the related communication media, additional characteristics need to be captured.

Thus, the goal of the proposed concept is to give the communication analysts a better modelling tool and analysis method for communication processes. The tool and method should support the planning and maintenance of a communication infrastructure tailored to the process specific communication needs.

3.2 Scope and Stakeholders

The scope of the presented concept concentrates on the internal communication of an organisation. Thus, only users, processes, and communication infrastructure from within one organisation are considered. Referring to the traditions of communication theory defined by Craig, the concept focusses on communication aspects derived from the semiotic and the cybernetic traditions. Aspects derived from the rhetorical, phenomenological, sociopsychological, sociocultural, or critical tradition are not considered.

On the most basic level, there are the *users* with a need to exchange information through some communication medium. Parts of this group are the *managers* who also decide on the communication policy defining the communication infrastructure. The *communication analysts* are specifically trained and support the managers by conducting surveys and by assembling reports regarding the communicational situation. Responsible for the implementation of the infrastructure are the *administrators*, who take care of hard- and soft-

ware installations and their maintenance. Out of the involved parties described above, the presented concept targets the communication analysts and the users. The analysts make use of the new modelling tool and analysis method in order to provide a thorough assessment to the managers. The users provide feedback about their communication requirements during interviews. Even though all of these users belong to the same organisation, they can be distributed across multiple geographical locations, between different organisational units, and over a range of hierarchical levels.

One or more managers from an organisation or an organisational unit are responsible for a comprehensive communication policy. The policy covers aspects such as information security, communication hierarchies, or openness. Based on this policy, they define what kind of communication infrastructure should be used in the organisation.

Based on the directives from the managers, the administrators are responsible for the implementation and maintenance of the communication infrastructure. The Infrastructure often consists of hard- and soft-ware or could also be bought as a Software-as-a-Service (SAAS) package.

The users employ the communication infrastructure for their usual collaborative work. During regularly conducted interviews, they provide feedback to the communication analysts regarding their communication requirements and they report occurrences of communication issues.

Parallel to their other activities, the communication analysts stay up-to-date by analysing the use of the currently deployed communication infrastructure and by monitoring upcoming new communication media as possible future solutions. They also analyse the

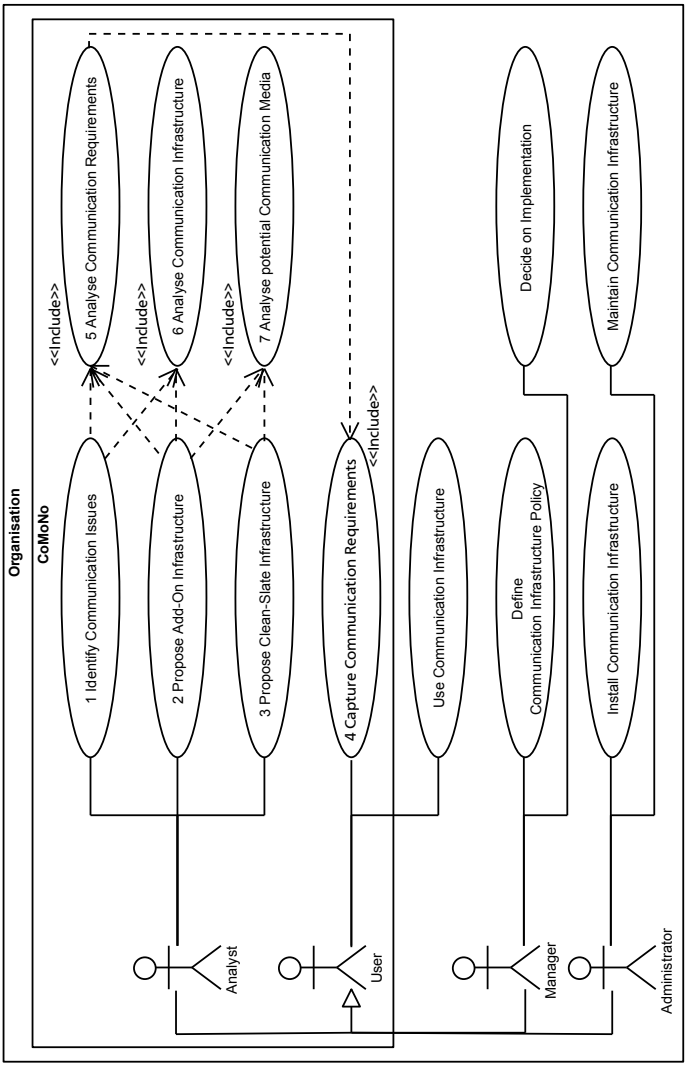

Figure 3.1: Use cases

communication requirements arising from the communication processes by conducting interviews with the users. Based on these insights, they compile reports about the current state for the managers and provide proposals for new or updated infrastructure. Considering the proposed changes, the managers instruct the administrators to implement the changes (see Figure 3.1).

3.3 Use Cases

Three main use cases reflect the intent of the analysts to understand and improve the communication in their organisation: the identification of communication issues, the proposal of additional communication infrastructure, and the proposal of a clean slate communication infrastructure. Four included use cases support the main use cases, by providing the necessary information: the capturing of the communication requirements of the users, the analysis of their requirements, the analysis of the currently installed communication infrastructure, and the analysis of potential new communication media.

Use Case 1 - Identification of communication issues: The managers of an established team with existing communication infrastructure need a clear understanding how the well the various communication intensive processes and the communication infrastructure fit together. They engage the communication analysts to perform the necessary surveys and to compile the information into a report. The report should highlight the discovered issues and bottlenecks.

Use Case 2 - Proposal of add-on infrastructure: The managers of a team want to improve the existing infrastructure by adding a limited

number of new communication media to the infrastructure. They ask the communication analysts, to provide improvement scenarios extending the available infrastructure. Based on the report provided by the analysts, the managers then instruct the administrators to reconfigure the existing communication infrastructure and install the necessary hard- and software to provide the additional services.

Use Case 3 - Proposal of clean-slate infrastructure: The managers of a team decide to set-up a new communication infrastructure without considering the existing solutions as boundaries. They ask the communication analyst, to provide a number of possible scenarios, which need to cover all of the current communication requirements. Using the analysts' report, they instruct the administrators to install the necessary hard- and software to provide the new communication services.

Use Case 4 - Capturing of communication requirements: In order to capture the communication requirements of the individual users, the analysts conduct interviews with them. The basic structure of the communication of the users, who exchanges information with whom about what, as well as more detailed requirements regarding how this information should be exchanged are acquired during these interviews.

Use Case 5 - Analysis of communication requirements: The analysts examine the captured requirements regarding general patterns.

Use Case 6 - Analysis of communication infrastructure: The analysts compile a list of currently available communication media and their capabilities. These can then be compared to the communication requirements of the users.

Use Case 7 - Analysis of potential communication media: With the development of communication technologies, new communication media may emerge. The analysts keep up-to-date with the recent developments and compile a list of potential communication media and their capabilities.

3.4 List of Requirements

The following functional requirements for the concept are specified based on the overall goal, the scope, the stakeholders, and the use cases:

R1: Communication Media and Process Characteristics

Description: Define characteristics that describe in detail the capabilities of communication media and the requirements of communication processes. These characteristics derive from recent findings of communication theory.

Rationale: These characteristics are necessary in order to understand the capabilities of communication media and the requirements of communication processes regarding the supporting communication media.

Fit Criterion: The defined characteristics must be fine-grained enough in order to clearly differentiate the communication media available in a product development context.

R2: Dissimilarity Coefficient for Characteristics

Description: The dissimilarity coefficient measures the matching between the requirements and the capabilities of communication processes and communication media.

Rationale: In order to estimate which of two communication process and communication media combinations matches better, a reproducible measure for their fit is needed.

Fit Criterion: All characteristics shared between process and medium are taken into account in order to calculate the dissimilarity coefficient. Using the coefficient, it must be possible to rank a given list of communication process and communication media combinations.

R3: Communication Model

Description: Define a communication model, which captures who is communicating with whom about what. The model also needs to take the characteristics defined in requirement R1 into account.

Rationale: A more detailed communication model is necessary in order to propose a well-suited communication medium for a given context.

Fit Criterion: The new communication model must contain all elements necessary to represent who is exchanging which information with whom in what manner. The individual elements must express the characteristics derived from requirements R1.

R4: Communication Model Notation

Description: Provide a visual notation for the central elements defined by the new communication model.

Rationale: A visual notation of the model enables intuitive interaction with it. It also enables the communication analysts to easily explain the model to non-technical users during the interview process.

Fit Criterion: A visual notation for the central elements and characteristics of the communication model must be provided. More than 50% of users must consider the visual notation helpful during the interview.

R5: Track Deployed Communication Media

Description: Provide a way to keep track of the currently deployed communication media, to which user they are available, and what their characteristics are.

Rationale: For subsequent analysis steps, it is necessary to know which communication media are available to which user in the organisation.

Fit Criterion: A way to track the communication media available to the users of the organisation and their characteristics must be provided.

R6: Identify Issues

Description: Define a process to identify discrepancies between the communication requirements captured in the model and the communication media available to the users.

Rationale: This analysis identifies bottlenecks in the *as-is* state, which is a necessary first step to better understand the current situation and derive countermeasures.

Fit Criterion: It must be possible to identify issues and bottlenecks based on a specific communication model enriched with advanced characteristics and the information about the currently available communication media.

R7: Track Potential Communication Media

Description: Provide a way to keep track of which communication media are potentially available and what their characteristics are.

Rationale: In order to identify possible improvements by introducing new communication media, a comprehensive list of potential candidates needs to be compiled and maintained.

Fit Criterion: A way to track potential communication media and their characteristics must be provided.

R8: Propose Clean-Slate Communication Infrastructure

Description: Define a process that proposes improvement scenarios based on potential communication media without considering currently deployed communication media. The process also needs to consider management requirements such as maximum number of deployed communication media or the general communication policy.

Rationale: This process proposes one or more solutions to the question "What combination of communication media covers the most communication requirements?"

Fit Criterion: The combination of communication media proposed by the process must minimise the discrepancies between requirements and media characteristics.

R9: Propose Add-On Communication Infrastructure

Description: Define a process that proposes improvement scenarios based on potential communication media while at the same time considering deployed communication media.

Rationale: Similar to the previous requirement, this process provides a solution to the question "What additions to the cur-

rently deployed communication infrastructure would reduce the issues the most?"

Fit Criterion: The combination of communication media proposed by the process must include the currently deployed communication infrastructure and must minimise the discrepancies between requirements and media characteristics.

The non-functional requirements are:

R10: Minimal Deviation from Standards

Description: The newly defined communication model and its notation should deviate as little as possible from established communication modelling standards.

Rationale: In order to reduce the effort of adapting to the new model and notation, both should stick as closely as possible to the standards they are based on.

Fit Criterion: The modelling techniques for the common basis between the standard and the newly derived model and notation must not be changed. An analyst, who can model in the existing standard, must not need to learn new concepts in order to apply the standard elements in the model and notation.

R11: Clear Visual Language

Description: The visual language of the adapted notation should be simple, clear, and easy to print in black and white.

Rationale: A simple and clear presentation of the additional information is necessary in order to grasp a diagram quicker. Even though many office printers today allow for colours, fax machines generally only transmit black and white, which should not alter the readability of the notation.

Fit Criterion: More than 50% of users must consider the visual language easy to understand and the readability of the symbols must not be altered by a black and white print.

3.5 Conclusion

Summarising the previous sections, the overall goal is to provide a model and notation of communication processes to support the analysis and planning of communication infrastructure. This model and notation must extend existing standards and it must take findings of media selection theories into account. The essential use cases are the analysis of the modelled communication process characteristics in comparison to the characteristics of the available communication media, the planning of a new set of communication media starting from scratch, and the planning of a suitable set of media to be added to the currently installed ones. The central user-group targeted by the approach is the communication analysts who use the model and notation as a supporting tool. Table 3.1 provides a compact overview of the requirements, their fit criteria, and their related use cases.

#	Requirement	Fit Criterion	Use Cases
1	Communication Media and Process Characteristics	The characteristics are fine-grained enough in order to differentiate communication media	1-7
2	Dissimilarity Coefficient for Characteristics	A list of conversation and media combinations can be ranked	1-3
3	Communication Model	The model can represent who is exchanging which information with whom in what manner	1-7
4	Communication Model Notation	>50% of the users consider the visual notation helpful during the interview	4
5	Track Deployed Communication Media	It is possible to track the communication media available to the users	6
6	Identify Issues	Issues can be identified based on a specific communication model and currently available media	1
7	Track Potential Communication Media	It is possible to track potential communication media	7
8	Propose Clean-Slate Communication Infrastructure	The additional media minimise the discrepancies with requirements	3
9	Propose Add-On Communication Infrastructure	The proposed media combination minimises the discrepancies with requirements	2
10	Minimal Deviation from Standards	The analyst can model in the base standard without learning new methods	4,5
11	Clear Visual Language	>50% of the users consider the visual language easy to understand	4,5

Table 3.1: Overview of requirements

Chapter 4

Concept

Chapter 2 described recent developments in product development processes and highlighted the increasing intensity and complexity of communication due to approaches like Simultaneous Engineering, trust management, and agile project management. In addition, the recent adoption of Web 2.0 concepts in enterprise environments furthers this development. In order to build a basis for the analysis and management of these communication processes, the chapter also reviewed media selection theories from the research field communication theory. Moreover, it showed that a stronger focus on communication in business process modelling approaches such as BPMN leads to better results of re-engineering projects.

In conclusion, a new approach integrating findings from communication theory and business process modelling is required in order to support the modelling, analysis, and planning of increasingly intensive and complex communication processes, which occur in product development.

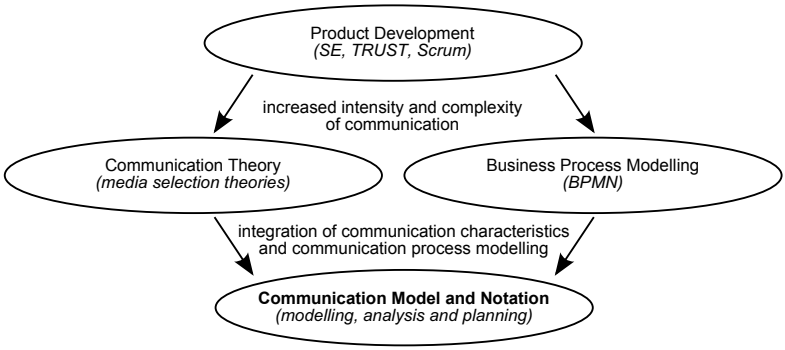

Figure 4.1: Rationale of the CoMoNo concept

Following this rationale (see Figure 4.1), this dissertation proposes a concept supporting analysis and planning of communication infrastructure based on an enhanced model and notation. This new model and its notation focus on the characteristics of communication processes and communication media. The central goal is to give the communication analysts a better modelling tool and analysis method to argue why certain changes in the communication infrastructure are necessary. Figure 4.2 provides an overview over the general process, which governs the CoMoNo concept.

The central aspects from the analysts' perspective are the modelling of communication media and processes, the analysis of the communication requirements, and the planning of a communication infrastructure adapted to the previous findings. The managers define the communication policy and decide on changes to the existing communication infrastructure based on this and the proposals provided by the communication analysts. Once they made the decision, the administrators implement the necessary communication infrastructure and provide access to the users. The users can then apply

the provided communication media in their daily business processes and provide feedback to the communication analysts. Aside the user initiated feedback, the communication analysts also conduct regular interviews with users, in order to keep up-to-date regarding their communication requirements.

As the CoMoNo concept focusses on the support of the communication analysts, this chapter will explain the three essential aspects of modelling, analysis, and planning in the following sections. The modelling aspect is split into two perspectives, the meta-model, which defines what elements are available for a concrete model, and the notation, which defines how these elements are visually represented in diagrams. The analysis then uses these modelling tools in order to define the characteristics of potential communication media, review the currently available communication infrastructure, and capture the communication requirements of the targeted users. Based on the findings of the analysis, the planning derives proposals for either a clean-slate or an add-on communication infrastructure.

4.1 Modelling

In general, a model is an abstract representation of a real phenomenon. Because a model is created for a specific and pragmatic reason, it reduces the real phenomenon to the relevant aspects. Depending on the intended application, a model commonly idealises the real world by simplifying assumptions or reducing irregularities, which have a negligible impact. A model aims to improve the understanding of the real phenomenon and thus enables the user to derive conclusions about the effects of changes in the real world. By pro-

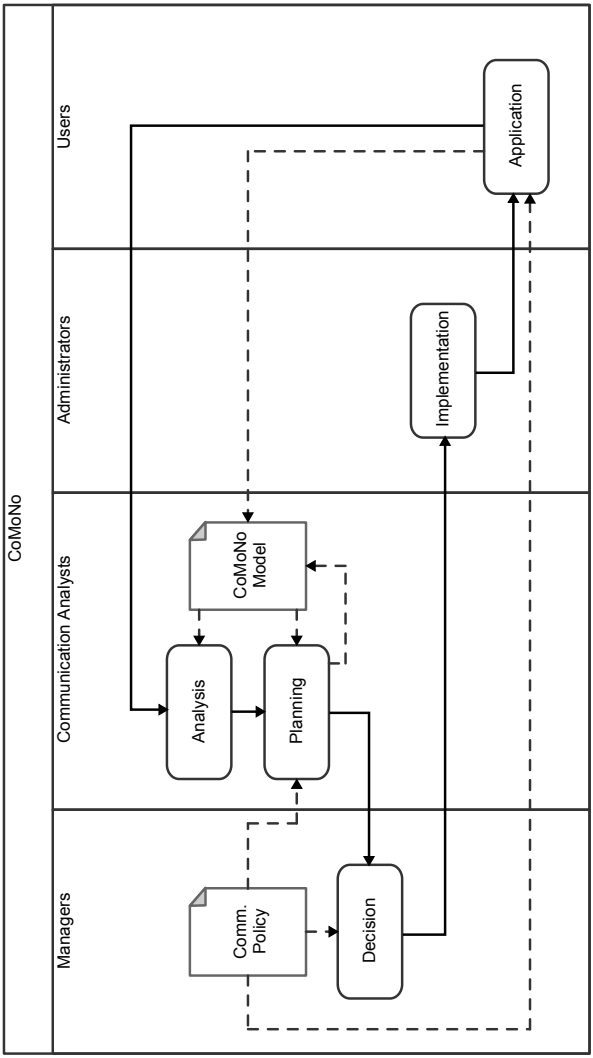

Figure 4.2: Overview of the CoMoNo process

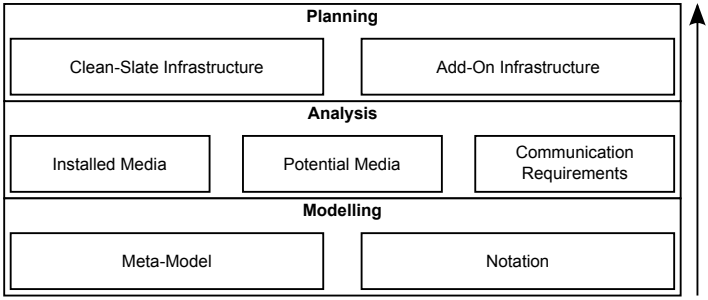

Figure 4.3: Structure of the concept

viding a common ground, it also supports the exchange and collaboration between the different users of a model and enables them to compare results modelled by different users.

The meta-model defines the elements available to the model and their possible relationships to one another. Based on the semantics provided in the meta-model, automated analysis becomes possible. The notation on the other hand provides a visual presentation to the user of the model, enabling the intuitive interaction with the elements and their relationships (see Figure 4.3). The meta-model and notation described in the following sections, represent communication processes between multiple participants. The model supports the analysis of communication processes and their relationship to the according communication infrastructure.

4.1.1 Meta-Model

The meta-model of the CoMoNo concept is based on the Conversation meta-model of BPMN 2.0 (see Section 2.3.2) and extends it with more detailed meta-data. This additional meta-data is needed in order to specify the media characteristics and communication require-

ments defined in the requirements R2 and R4 (see Chapter 3). The UML class diagram shown in Figure 4.4 provides a general overview and the following sections explain each element in more detail.

The three core-elements of the meta-model are the `Participant`, the `Conversation`, and the `CommunicationMedium`. The former two as well as the `ConversationNode` and `SubConversation` classes are adaptations from the standard Conversation meta-model. Aside these, there are a number of additional classes, reflecting the CoMoNo additions: The two classes `Level` and `Location` denote the hierarchical and spatial position of a `Partcipant`, the association class `Role` specifies whether a `Participant` is a sender, receiver, or both in the context of a specific `ConversationNode`, and the `CommunicationIssue` class is used to highlight identified problems in a CoMoNo model.

Classes

`Participant`**:** This reflects who is taking part in an information exchange and can be either an individual person or an abstract group of persons. Each `Participant` specifies the spatial `Location`. Depending on the context of the model, this could be a geographic location represented by latitude, longitude, and elevation or a company specific location represented by the complex, building, level, and room number. Using an according implementation of a distance metric, one can derive a measure of distance from two given locations. The association class `Role` and its implementations `Sender`, `Receiver`, `SenderAndReceiver` determine whether a `Participant` provides information, receives information, or does both in the context of one specific `Conversation`. In order to simplify the model and to avoid

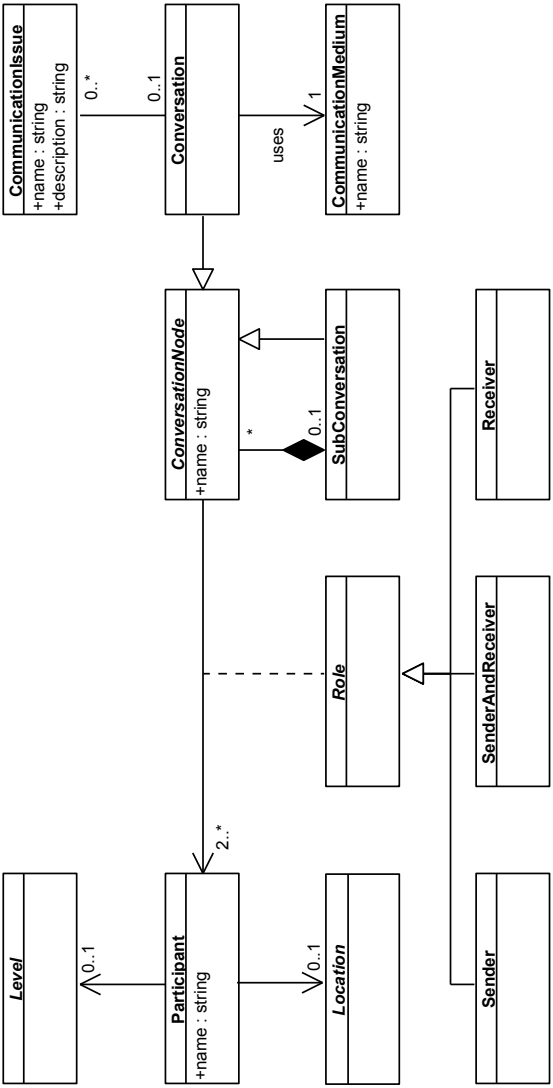

Figure 4.4: CoMoNo meta-model

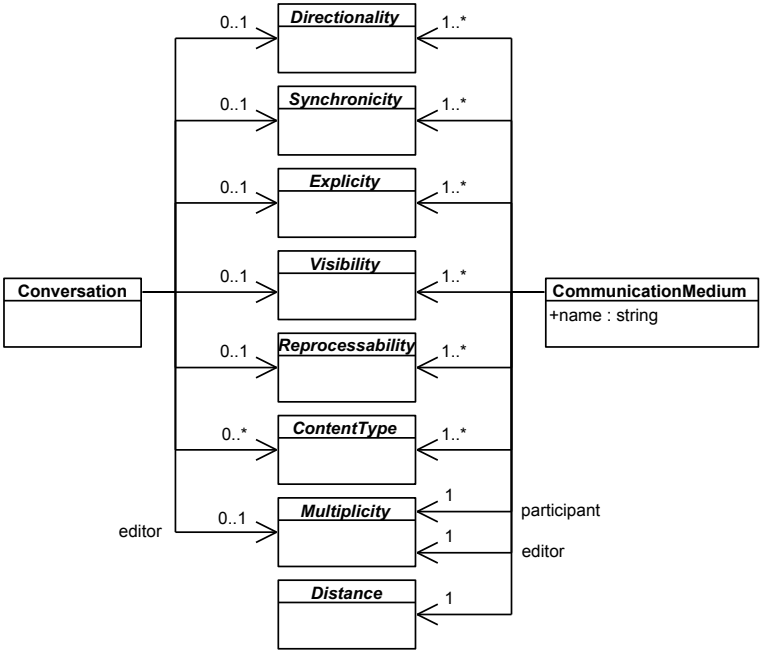

Figure 4.5: CoMoNo characteristics and their associations

creating large numbers of participant instances, a single participant who represents an abstract group of individuals (e.g. readers of a newspaper) can specify a multiplicity. If no multiplicity is set, a multiplicity of one is assumed.

`Conversation`**:** According to the BPMN 2.0 specification, "a Conversation is the logical relation of Message exchanges. The logical relation, in practice, often concerns a business object(s) of interest, e.g., Order, Shipment and Delivery, and Invoice." As a message exchange involves two `Participants`, a `Conversation` is associated to at least two. In order to be able to define a `Conversation` on a more detailed level, it is possible to define a `SubConversation` which itself can contain multiple conversations. Both `Conversation` and `SubConversation` derive from the abstract `ConversationNode` and thus share the associations defined on that level. So far, the structure of conversation related classes adheres to the BPMN 2.0 standard but the CoMoNo meta-meta-model extends this by adding multiple associations to the characteristics defining the requirements of an individual `Conversation` (see Figure 4.5).

`CommunicationMedium`**:** This class is specific to the CoMoNo meta-model and describes a communication medium and its capabilities. Each `Conversation` is associated to at least one `CommunicationMedium` used to transmit the involved messages. The capabilities of a medium are represented by associations to characteristics (see Figure 4.5).

`Role`**:** This specification is context specific and is thus modelled as an association class. For each combination of `Participant` and `ConversationNode`, an independent sender/receiver specification is captured. This tells whether the `Participant` provides or consumes

information. In the context of a bi-directional conversation, both participants have both roles.

`Level`**:** This describes the hierarchical position of a participant and must be adapted to the specific context of a modelling application.

`Location`**:** In order to calculate the distances between the `Participants` of a `Conversation`, the spatial position of each `Participant` needs to be captured. Similar to the `Level`, the way locations are specified must be adapted to the specific context.

`CommunicationIssue`**:** As communication issues are identified during the modelling process, they need to be captured in the context of the `Conversation` in which they occur. They contain a description that explains the cause of the identified issue.

Characteristics

Characteristics with a discrete number of possible values are modelled as abstract classes with the possible values as subclasses. The characteristics can be categorised into three groups: characteristics of the participant, characteristics directly shared between the conversation and the communication medium, and characteristics that need to be evaluated from a concrete model. Shared characteristics like synchronicity, directionality, explicity, visibility, reprocessability, editor multiplicity, and conteny type are explicitly specified in a realised model; other characteristics like participant multiplicity and distance need to be calculated from the participants assigned to a conversation and their multiplicities. The class diagram in Figure 4.6 and Table 4.1 provide a summary of the characteristics and their defined values.

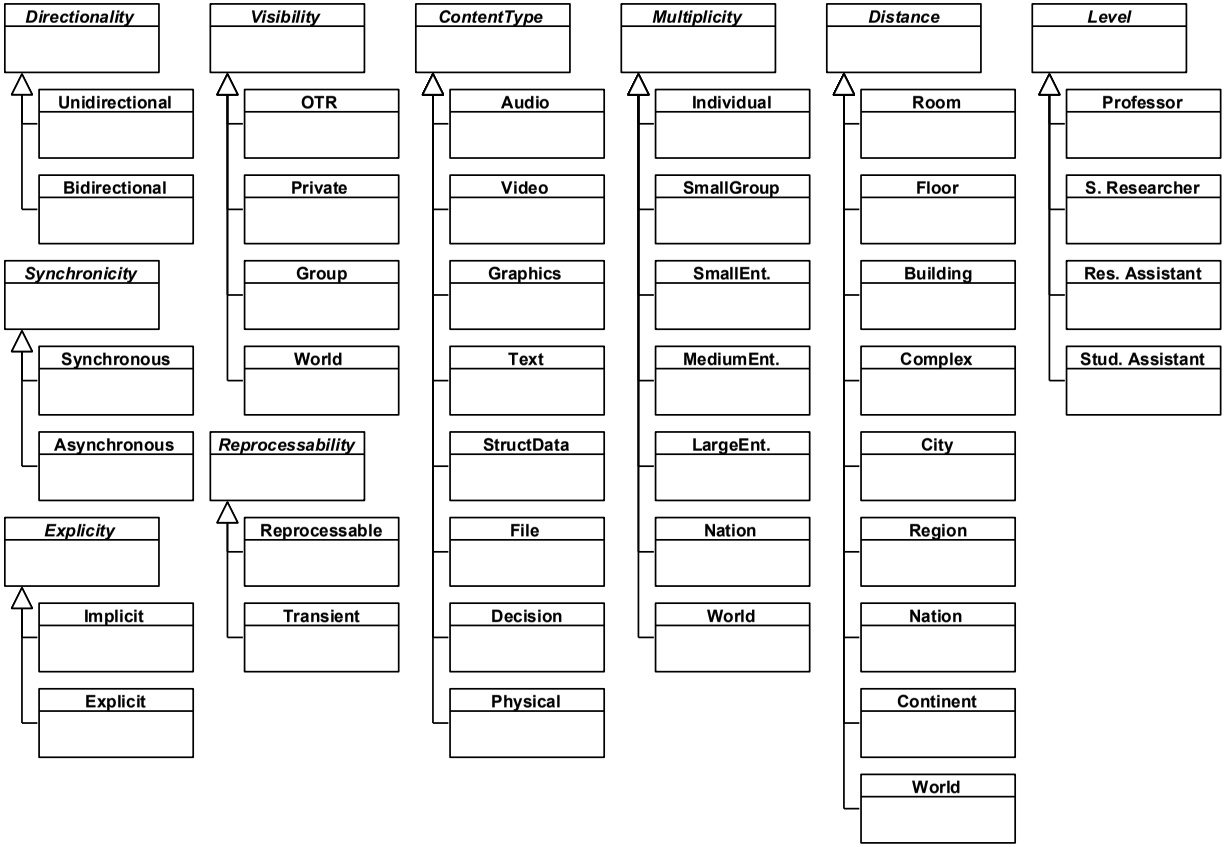

Figure 4.6: CoMoNo characteristics

Directionality: The directionality of a conversation defines whether the roles of sender and receiver are fixed or can be switched. In a uni-directional conversation, the receiver cannot become a sender and thus cannot reply to the information received. In a bi-directional conversation, at least two participants are senders. The media richness theory (see Section 2.2.4) refers to this characteristic as "feedback" and considers it an important factor positively influencing "media richness" [DL84; DLT87].

Uni-Directional: newspaper, radio, television, presentation
Bi-Directional: mail, telephone, video conference, meeting, wiki

Synchronicity: If a conversation is synchronous, both parties need to be present at the same time. In an asynchronous conversation, the sender can provide the information, even if the receiver is currently not available. As with the directionality mentioned above, the media richness theory also considers the synchronicity, or as it calls it the "immediacy", an important contribution to "media richness". In general, media richness theory merges both characteristics together and only speaks of "immediacy of feedback". Media synchronicity theory (see Section 2.2.5) on the other hand, offers a more differentiated perspective on synchronous feedback [DV99; DFV08]. While it considers synchronicity an important factor in improving understanding for similar reasons provided by media richness theory, it also argues that synchronous feedback can have a negative impact on conveyance of information that requires deliberation. The authors argue, that media which enable synchronous feedback, create the according expectations and thus limit deliberation. This in turn could lead to premature action. Another indirect factor influencing the possible synchronicity is the location of the participants.

If they are spread out across different continents and thus different time zones, synchronous communication is often not possible, as not everyone is available at the same time.

Synchronous: face to face, presentation, telephone, radio, chat
Asynchronous: fax, email, blog, wiki, podcast, shared drive

Reception: Just having sent a message, does not always guarantee, that the intended recipient received it. Even in a face-to-face conversation, an explicit nod with one's head might be necessary to show that the message was received. Additional protocols, such as the receiver repeating the received message, can further reduce the risk of a misunderstanding. Electronic communication media often automate this process and inform the user of the outcome. As the receiver at least needs to acknowledge the reception of a message, explicity implies a minimal level of bi-directionality.

Explicit: face to face, telephone, meeting, sometimes email
Implicit: book, radio, television, blog, wiki, shared drive

Visibility: When two persons communicate, both need access to the content of the message. In an environment with many potential participants, the situation becomes more complex and more fine-grained control of access or visibility is necessary. A private message should only be visible to those directly addressed, but in a collaborative environment it can be useful, if even not directly addressed members of the group can view the message. Some messages are not even addressed to anyone at all, but are meant for the general public. A special case arises, when the content of the message should be off-the-record so that none of the involved parties can prove, what

the other parties stated. The off-the-record capability aside, this visibility model is aligned with the Portable Operating System Interface (POSIX) specification [IEE08], private resembles the “owner class”, group resembles the “group class”, and world resembles the “other class”. Although this characteristic defines the circle of participants who are able to view the content of a conversation, it does not specify the security provided by the medium. Encryption and other security measures are not considered.

OTR: face to face, telephone; Private: mail, email, chat
Group: meeting, mailing-list, video conference
Public: book, radio, television, blog, wiki, presentation

Reprocessability: The reprocessability defined by the media synchronicity theory (see Section 2.2.5) describes the ability to access content of a conversation even after the conversation took place. While this is true for most asynchronous media, also synchronous media can be made somewhat reprocessable by arranging a dedicated note-taker and by providing meeting-minutes. It is also directly linked to the visibility of the conversation, as the participant will only be able to review those contents, which are accessible. The ability to search through content of a conversation is related to this characteristic, as only available content can be searched. While early information systems focussed on categorisation of information in order to retrieve it, the ability to search in vast amounts of content has been a major enhancement driven by recent technologies such as McAfee's SLATES based Enterprise 2.0 (see Section 2.2.7).

Reprocessable: blog, wiki, DMS
Transient: face to face, telephone, meeting

ContentType: Media Richness Theory addressed this characteristic as “multiple cues” and “language variety” and defines these as “array of cues [which are] part of the message” or respectively “the range of meaning that can be conveyed with language symbols”. In this sense, numbers can convey more precision, while natural language and gestures can communicate a broader range of concepts and ideas (see Section 2.2.4). The “symbol sets” introduced by Media Synchronicity Theory extend Shannon’s symbol type concept and include the above definitions. Dennis states that there is a broad range of symbols available to humans and that many media support the simultaneous transmission of multiple symbol sets. The ContentType characteristic is thus based on the symbol set definition and represents an extendible list of possible content types. Initial suggestions are listed in the examples below.

Physical: handshake
Audio: telephone, podcast, radio
Audio & Video: video conference, vodcast, television
Text: micro blog, chat, SMS
Text & Graphics: mail, fax, email
Structured Data: database
Decision: web decision tool, DSS

Multiplicity: According to the communication model introduced by Shannon (see Section 2.2.3), a message always follows a one-to-one pattern: one sender and one receiver. As a conversation can aggregate multiple messages and as each participant can take different roles, two multiplicities are necessary to define a conversation: How many participants take part in a conversation and how many

of them are editing the content simultaneously. While the multiplicities derived from the model represent concrete numbers, the multiplicities defining the capabilities of communication media are defined on seven levels: individual (I, 1), group (G, < 10), small enterprise (SE, < 50), medium enterprise (ME, < 250), large enterprise (LE, $< 2.5M$), nation (N, $< 1.5B$), world (W, $< 10B$). The group size is based on recent studies regarding team compositions [Ste06; Mue12], small and medium enterprise sizes are derived from the specification of the European Commission [Eur05], the large enterprise scale is based on Wal-Marts annual report of 2012 [Wal12; Bas07], the nation scale is based on the China, the world's most populous nation, and world scale is based on the United Nations report on World Population Prospects [Uni09].

One-to-one: face to face, telephone, fax
One-to-many: book, presentation, blog
Many-to-many: mailinglist, wiki, shared-drive

Distance: The distances derived from the locations of the participants involved in a conversation are essential criteria for the selection of the appropriate communication media. A face-to-face conversation is not possible if the participants are spread out across multiple cities or even countries. Yet, if the participants are sitting in the same room, they will usually not use the telephone to communicate. The levels used for this characteristic roughly follow a base 10 exponential law: room (D0, $10^0 m$), floor (D1, $10^1 m$), building (D2, $10^2 m$), complex (D3, $10^3 m$), city (D4, $10^4 m$), region (D5, $10^5 m$), Nation (D6, $10^6 m$), Continent (D7, $10^7 m$), World (D8, $^1/_5 * 10^8 m$). A CoMoNo implementation needs to include a distance metric that calculates a distance value from two given locations of participants.

Room: face-to-face
Floor: coffee machine
Building: blackboard
Complex: spontaneous meeting
City: local radio
Region: regional newspaper
Nation: national TV
Continent&World: mail, electronic media

Table 4.1 summarises the details provided above and introduces the symbols, scales, encodings, and icons used for the individual characteristics.

4.1.2 Notation

In order to facilitate the intuitive user interaction with the model, a graphical notation defining the presentation of the individual elements is required. Similar to the meta-model introduced in the previous section, the notation is based on the BPMN 2.0 conversation diagram and extends it with symbols for the additional metadata. In general the notation focusses on conversations, participants, and their associations. Conversations are represented as hexagonal shapes, participants as rectangles with sharp corners, and the associations as solid lines connecting conversations and participants. Deviating from this standard BPMN 2.0 conversation diagram notation, the participants also show their multiplicity, while the conversations show the editor multiplicity. Additionally, symbols representing the state of the essential characteristics directionality, synchronicity, reception, visibility, reprocessability, and participant role enrich the

Characeristic	**Symbol**	**Scale**	**Encoding**	**Icons**
Role	*Role*	poly-nominal	sender (S), receiver (R), sender and receiver (SR)	
Synchronicity	*Syn*	poly-nominal	asynchronous (a), synchronous (s), both (as)	
Directionality	*Dir*	poly-nominal	uni-directional (u), bi-directional (b), both (ub)	
Reception	*Rec*	poly-nominal	implicit (i), explicit (e), both (ie)	
Reprocessability	*Rep*	poly-nominal	reprocessable (r), transient (t), both (rt)	
Visibility	*Vis*	poly-nominal	OTR (O), private (P), group (G), world (W)	
Content	*Cont*	poly-nominal	audio (Au), date (Da), decision (De), file (Fi), graphic (Gr), physical (Ph), struct. data (SD), table (Ta), text (Te), video (Vi)	
Editor Multiplicity	*eMult*	ratio		
Participant Multiplicity	*pMult*	ratio		
Distance	*Dist*	ratio		

Table 4.1: Roles and characteristics with their symbols, scales [Ste46], encodings, and icons

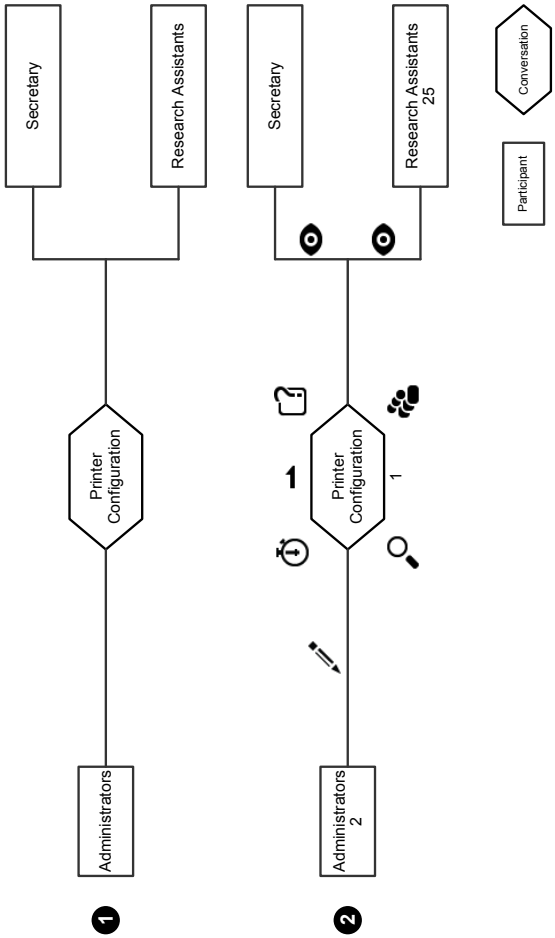

Figure 4.7: Comparison of standard BPMN conversation and CoMoNo diagram

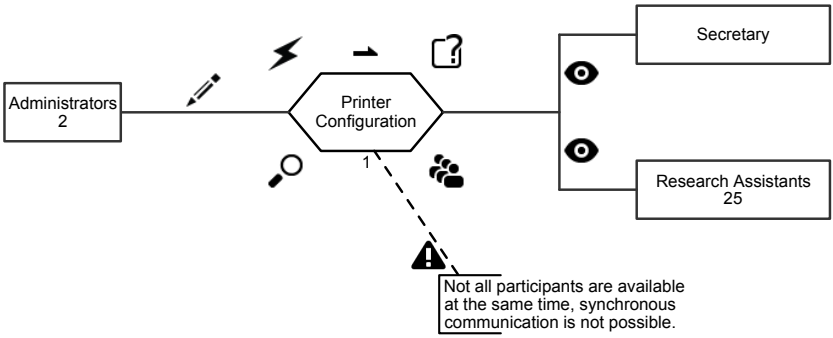

Figure 4.8: CoMoNo diagram containing an issue

conversation notation. Table 4.1 provides a list of the different symbols for these characteristics. The lines representing the associations between participants and conversations also show the role of each participant in a specific conversation.

Sub-figure 1 of Figure 4.7 shows the standard BPMN 2.0 conversation diagram notation. Sub-figure 2 shows the full notation defined by the CoMoNo concept containing additional meta-data presentations for conversations, associations, and participants.

In this case, the two administrators provide information about the configuration of the shared printers to the secretary and to up to twenty-five research assistants. Not all of these participants are available at the same time, only the administrators can change the information and it is not necessary to know explicitly, who received the information. Thus the information is shared asynchronously, unidirectional, and with implicit reception. Moreover, it is only visible to the group, who can also reprocess the information later.

Figure 4.8 shows a CoMoNo diagram with slightly change characteristics. Now the printer configuration is supposed to be shared

synchronously, which obviously leads to an issue, as not all participants are necessarily available at the same time. Such an identified communication issue is shown in this model, highlighting the conversation that is problematic.

Some of the meta-data described in Section 4.1.1 is not visually represented by the notation in order to enhance the readability by keeping it simple and uncluttered. Future CoMoNo modelling-tools are responsible for providing additional user interface elements to view and edit these attributes. The participant symbols do not visualise their level and location, and the conversation symbols do not show their attributes for required content types or the used medium.

4.1.3 Dissimilarity Coefficient for Communication

In order to compare the resemblance between a number of object pairs, a measure describing their similarity or dissimilarity is needed. Resemblance coefficients calculate a single value for this measure based on the properties of the compared objects. The two types of resemblance coefficients, similarity coefficient and dissimilarity coefficient, only differ in their direction. The former delivers a higher value for closer resemblance, while the latter gives higher values for greater differences [Rom04].

The challenge to create a dissimilarity coefficient as demanded by requirement R2 is to integrate the different types of characteristics into one value. For the poly-nominal characteristics $p \in \{Syn, Dir, Rec, Rep, Vis, Cont\}$, the dissimilarity coefficient of a conversation C and a medium M $d_{C,M,p}$ is defined as:

$$d_{C,M,p} = \frac{|c_{C,p} \setminus c_{M,p}|}{|c_{C,p}|} \quad 0 \leq d_{C,M,p} \leq 1 \tag{4.1}$$

$d_{C,M,p}$	$c_{M,Vis} = \{O,W\}$	$\{G\}$	$\{P,G\}$	$\{O,P,G\}$
$c_{C,Vis} = \{P,G\}$	1.0	0.5	0.0	0.0
$d_{C,M,r}$	$c_{M,Dist} = 1\text{m}$	10^3m	10^6m	10^9m
$c_{C,Dist} = 10^6\text{m}$	1.0	0.5	0.0	0.0

Table 4.2: Examples for the dissimilarity coefficients for polynominal and ratio scale characteristics of a conversation and a medium. (d:dissimilarity coefficient, C:conversation, M:medium, p:polynominal scale, r:ratio scale, Vis:visibility, Dist:distance, O:OTR, P:private, G:group, W:world)

Here $c_{C,p}$ and $c_{M,p}$ are the sets of values for the characteristic p of the conversation C or medium M. For example if the conversation required both private and group visibility ($c_{C,Vis} = \{P,G\}$) and the medium only provided one of them ($c_{M,Vis} = \{G\}$), the coefficient would be $d_{C,M,Vis} = \frac{1}{2} = 0.5$. Table 4.2 lists some exemplary values for the coefficient.

For the ratio scale characteristics $r \in \{pMult, eMult, Dist\}$, the dissimilarity coefficient is defined as:

$$d_{C,M,r} = \begin{cases} 0.0 & \text{if } c_{C,r} \leq c_{M,r} \\ \dfrac{\log_{10}(c_{C,r}) - \log_{10}(c_{M,r})}{\log_{10}(c_{C,r})} & \text{if } c_{C,r} > c_{M,r} \end{cases} \qquad 0 \leq d_{C,M,r} \leq 1 \tag{4.2}$$

If a conversation takes place across a country ($c_{C,Dist} = 10^6\text{m}$) but the medium is only considered relevant for the distance of a complex ($c_{M,Dist} = 10^3\text{m}$), the dissimilarity coefficient would be $d_{C,M,Dist} = \frac{6-3}{6} = 0.5$. Table 4.2 provides a range of values for different combinations of conversations and media.

The combined dissimilarity coefficient $d_{C,M}$ for all characteristics $c \in p \cup r$ is defined as the sum of all individual coefficients $d_{C,M,c}$ in relation to the number of characteristics $|c|$:

$$d_{C,M} = \frac{\sum_{c \in p \cup r} d_{C,M,c}}{|c|} \quad 0 \leq d_{C,M} \leq 1 \tag{4.3}$$

As each individual dissimilarity coefficient is already normalised to the range 0 to 1, the combined coefficient is also normalised to this range. If no requirement for a characteristic c is specified by a conversation, $dC, M, c = 0$.

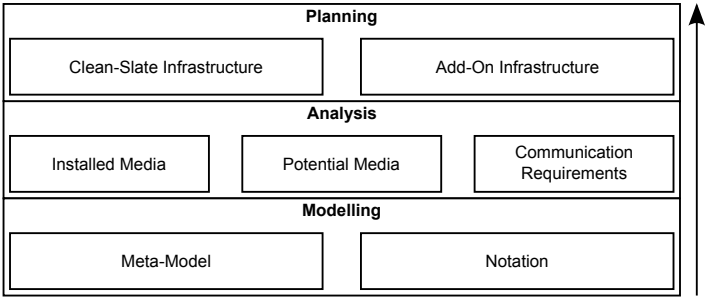

Figure 4.9: Structure of the concept

4.2 Analysis

The overall structure of the CoMoNo concept presented in Figure 4.9 shows three distinct aspects of the analysis section: The analysis of available communication media, of potential communication media, and of the process specific communication requirements. The first and second involve the capturing of the previously described communication characteristics for potential or currently installed communication media while the third focusses on the examination and modelling of business processes with a focus on their communication characteristics.

4.2.1 Analysis of Communication Media

As mentioned in Chapter 3, the targeted user group of the CoMoNo concept are the analysts who use the enhanced modelling tools to conduct their analysis of the communication processes and infrastructure. The first two analysis activities, described in the following sections, provide the foundation for well-informed decisions in the subsequent planning phase: “What are the characteristics of the cur-

rently installed communication media?" and "Which communication media are potentially available and what are their characteristics?"

In the first step, a table of the capabilities of all currently employed communication media is compiled following the template provided in Table A.1. The table uses two different variable encodings, poly-nominal and numerical. The characteristics synchronicity, directionality, reception, and reprocessability have all only two basic states but some media support both options and the final choice is up to the user. For example, email is most commonly used with implicit reception, but the user can choose to require an explicit confirmation of the reception. In this sense, the characteristics synchronicity, directionality, reception, and reprocessability have the additional state *both* and are thus modelled as poly-nominal variables. Another case is the characteristics visibility with its four different options and the possible forms of content, which are encoded as a comma or space separated text strings. In combination with a definite order of their elements, they can be treated as poly-nominal variables to some extent. The two characteristics distance and multiplicity are modelled as ratio-scale numerical variables.

In the second step, the analysts compile a similar table for potential communication media, i.e. those media which are currently not installed but which are viable regarding relevant business constraints like existing hardware or budget limits.

In both cases, currently installed communication media and potential future communication media, the captured capabilities resemble the common, regular case, not the uncommon extreme. Of course, a user could potentially send a normal email to thousands

of recipients by manually adding thousands of addresses, but this is usually not the case.

4.2.2 Analysis of Communication Requirements

The lengthier process of updating the communication model involves capturing the communication behaviour of the users and their communication requirements. In a first round of interviews, the basic structure of who is communicating with whom about what topic is aggregated and analysed. The question to be answered by this step is which users are the key-communicators, i.e. which users are involved in the most conversations and which conversations are the ones with the most participants. The second round of interviews focusses on these key-communicators and the users participating in key-conversations. Now the specific requirements of each participant and conversation are integrated into the comprehensive CoMoNo model. A template for the interview guideline can be found in Appendix A.

In addition to the issues already reported by the users, it is also necessary to identify any issues arising from discrepancies between the modelled requirements and the available communication media. This procedure (see Figure 4.10) includes loading all conversations represented by the CoMoNo model (see Template A.2. The initial list includes the requirements directly associated to the conversations. The following two steps aggregate the multiplicity and distance requirements from the participants for each conversation. Regarding the distance between all senders and receivers, the requirement demanding the longest distance prevails. The final table of conversation requirements is then compared to the characteristics of the available

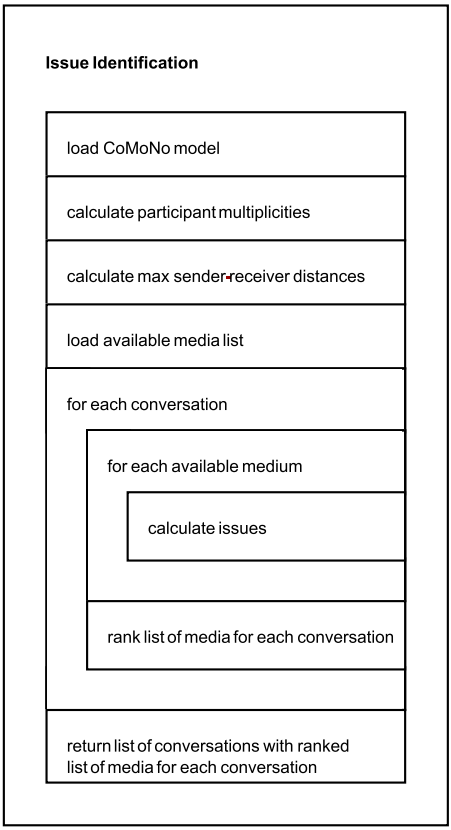

Figure 4.10: Issue identification procedure

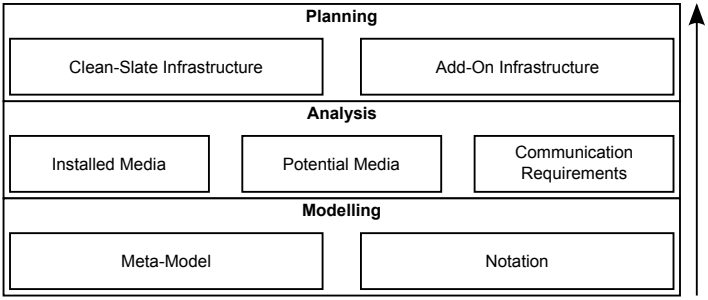

Figure 4.11: Structure of the concept

media, which was compiled previously. For each conversation in the table the match for all available media is calculated using the dissimilarity coefficient $d_{C,M}$ described in Section 4.1.3. For each conversation, a ranked list of communication media is stored.

4.3 Planning

There are two approaches for the planning of a proposal for a new communication infrastructure: clean-slate and add-on (see Figure 4.11). While the former assumes that the currently installed infrastructure can be changed or even completely removed, the latter keeps the current infrastructure as it is and only adds new media.

4.3.1 Planning of a Clean-Slate Infrastructure

As the planning of a clean-slate proposal does not take the current communication infrastructure as a fixed given, there are three potential ways to treat the installed media (see Figure 4.12). Sub-figure 1 shows the case in which all currently installed media are also considered potential media for a new proposal. Sub-figure 2 shows a case in

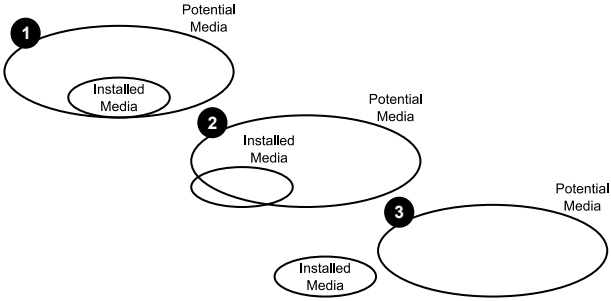

Figure 4.12: Potential media for a clean-slate proposal

which some of the current media are excluded from the list of potential media for a proposal. Sub-figure 3 shows the rare case that none of the current media should be considered in a new proposal.

The number of communication media to be considered in the new proposal (n) is set after the list of considered communication media for a clean-slate proposal has been decided on. Using the list of potential media, the list of conversations in the CoMoNo model, and the number of media to be proposed as input, the procedure to derive a customised proposal (see Figure 4.13) works as follows:

1. The list of conversations with their communication requirements, which has been created during the analysis phase (see Section 4.2.2), is loaded from the CoMoNo model.
2. The list of potential communication media together with their characteristics is loaded.
3. For all possible sets of potential media of cardinality n and each conversation, the set-members with the lowest dissimilarity coefficient $d_{C,M}$ regarding the current conversation are identified and the sum of the dissimilarity coefficients is calculated across all conversations. Now this sum is divided by the

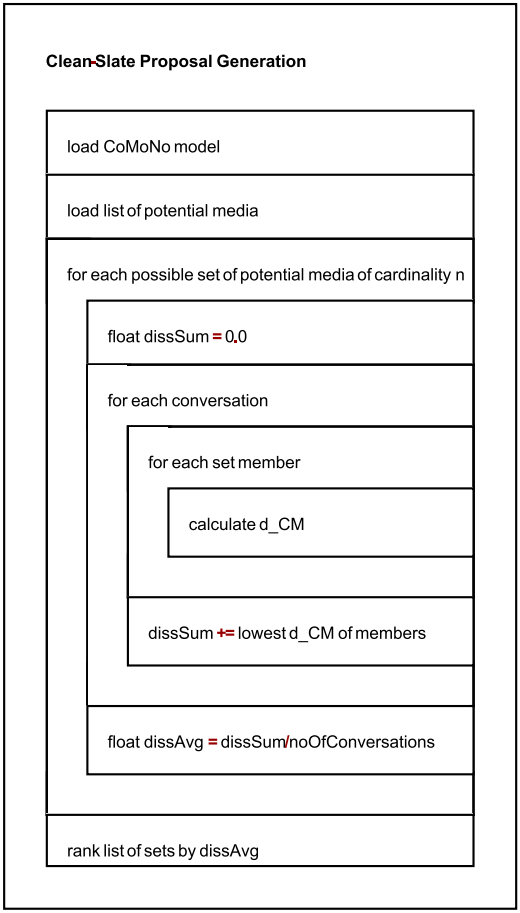

Figure 4.13: Clean-slate proposal procedure

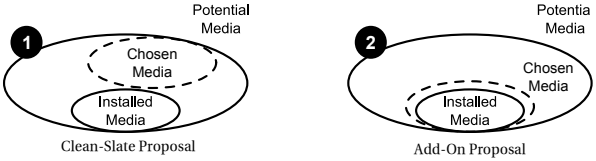

Figure 4.14: Potential media for an add-on proposal

number of conversations and is then assigned to the respective set of potential media.

4. The list of possible sets of potential media is sorted in ascending order according to each sets averaged sum of the dissimilarity coefficients, so that the best candidates are listed first.

4.3.2 Planning of an Add-On Infrastructure

The planning of an add-on proposal seems similar to the clean-slate case in which all currently installed media are included in the list of potential media. The difference between these two cases is that for an add-on proposal all current media *must* be included in the final proposal, while in the clean-slate case, they may be but do not have to (see Figure 4.14). This slight difference changes the procedure to generate an add-on proposal compared to the clean-slate case (see Figure 4.15):

1. The list of conversations with their communication requirements, which has been created during the analysis phase, is loaded from the CoMoNo model.
2. The list of current communication media together with their characteristics is loaded.
3. The list of add-on communication media together with their

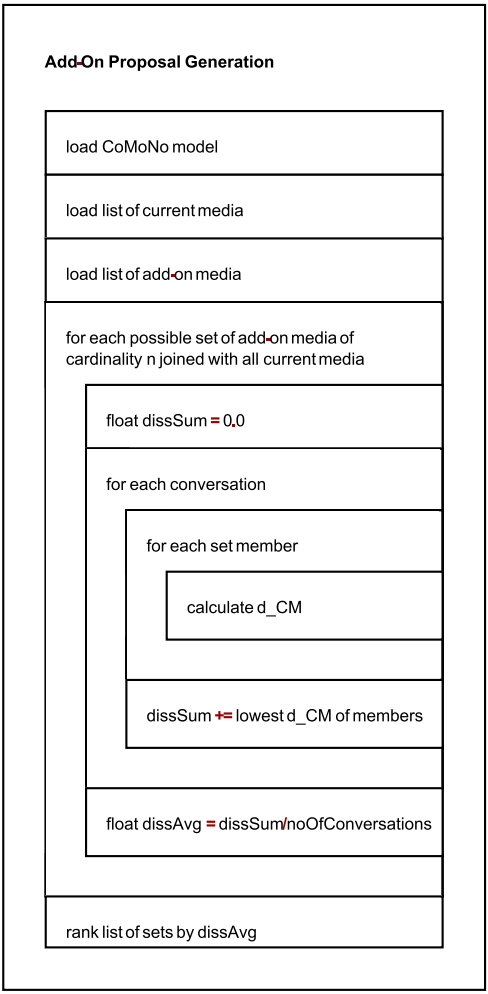

Figure 4.15: Add-on proposal procedure

characteristics is loaded.

4. For all possible sets of potential media of cardinality n joined with the set of current media and each conversation, the set-members with the lowest dissimilarity coefficient $d_{C,M}$ regarding the current conversation are identified and the sum of the dissimilarity coefficients is calculated across all conversations. Now this sum is divided by the number of conversations and is then assigned to the respective set of current and add-on media.
5. The list of possible sets of current and add-on media is sorted in ascending order according to each sets averaged sum of the dissimilarity coefficients, so that the best candidates are listed first.

4.4 Verification

The Institute of Electrical and Electronics Engineers (IEEE) Standard Computer Dictionary [IEE91] defines the two terms as follows:

> "Verification: The process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase."
>
> "Validation: The process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements."

In other words, verification evaluates whether the right thing was done, while validation checks whether the right thing was done right.

While verification focusses inwards, validation is targeted at external aspects such as customers [IEE11]. In this sense, this section will evaluate to what extend the proposed CoMoNo concept provides solutions regarding the requirements stated in Chapter 3. The validation by applying a prototypical implementation of the concept in a case study will be discussed in Chapter 5.

R1 - Communication Media and Process Characteristics: *The defined characteristics must be fine-grained enough in order to clearly differentiate the communication media available in a product development context.* The CoMoNo concept introduces communication characteristics based on the findings of media selection theories. Whether these characteristics clearly differentiate a set of communication media from the product development context can only be evaluated with the data provided in Chapter 5.

R2 - Dissimilarity Coefficient for Characteristics: *All characteristics shared between process and medium are taken into account in order to calculate the dissimilarity coefficient. Using the coefficient, it must be possible to rank a given list of communication process and communication media combinations.* The dissimilarity coefficient $d_{C,M}$ described in Section 4.1.3 derives a measure from all shared characteristics of conversations and communication media. The coefficient describes to what degree a medium deviates from the requirements of a conversation. How well this coefficient works in order to rank realistic combinations of conversation requirements and medium capabilities is validated in Chapter 5 using the data gathered during the case study.

R3 - Communication Model: *The new communication model must contain all elements necessary to represent who is exchanging*

which information with whom in what manner. The individual elements must express the characteristics derived from requirements R1. The CoMoNo model captures the basic structure of a conversation as provided by the BPMN Conversation Diagram. In addition to this generic information, it also describes the manner in which this communication takes place by including the additional characteristics directionality, synchronicity, reception, visibility, reprocessability, content type, editor multiplicity, participant multiplicity, role and distance (see Section 4.1.1).

R4 - Communication Model Notation: *A visual notation for the central elements and characteristics of the communication model must be provided. More than 50% of users must consider the visual notation helpful during the interview.* Out of the ten newly introduced characteristics only three, namely the content type, the distance, and the role, are not visually presented in the notation. They are not visualised, as their textual representations would overload the diagram. All other seven characteristics, directionality, synchronicity, reception, visibility, reprocessability, editor multiplicity, and participant multiplicity are presented by icon-graphics or numerically. The perception of the users will be evaluated in Chapter 5.

R5 - Track Deployed Communication Media: *A way to track the communication media available to the users of the organisation and their characteristics must be provided.* Template A.1 provides the basic structure necessary to capture the characteristics of available media. A standard spreadsheet application is sufficient to manage this information.

R6 - Identify Issues: *It must be possible to identify issues and bottlenecks based on a specific communication model enriched with ad-*

vanced characteristics and the information about the currently available communication media. Section 4.2.2 of the concept describes a method to identify mismatches between the currently installed communication infrastructure and the communication processes. It takes a CoMoNo model and a list of available media as input and delivers a list of conversations with issues as output. The application of this method to real data, gathered during the case study, will be evaluated in Chapter 5.

R7 - Track Potential Communication Media: *A way to track potential communication media and their characteristics must be provided.* Template A.1 provides the basic structure necessary to capture the characteristics of potential media. As with R5, a standard spreadsheet application is sufficient to manage this information.

R8 - Propose Clean-Slate Communication Infrastructure: *The combination of communication media proposed by the process must minimise the discrepancies between requirements and media characteristics.* The method described in Section 4.3.1 provides a ranked list of proposals combining different communication media in order to achieve a good fit with the communication requirements. The method uses a CoMoNo model, a list of potential media, and a desired number of media to combine as input and delivers a ranked list of possible media combinations. The application of this method to real data, gathered during the case study, will be evaluated in Chapter 5.

R9 - Propose Add-On Communication Infrastructure: *The combination of communication media proposed by the process must include the currently deployed communication infrastructure and must minimise the discrepancies between requirements and media charac-*

teristics. The method described in Section 4.3.2 provides a ranked list of proposals combining additional communication media with the existing ones in order to achieve a good fit with the communication requirements. The method uses a list of current media, a list of potential add-on media, and a desired number of media to add to the current ones as input and delivers a ranked list of possible media additions. The application of this method to real data, gathered during the case study, will be evaluated in Chapter 5.

R10 - Minimal Deviation from Standards: *The modelling techniques for the common basis between the standard and the newly derived model and notation must not be changed. An analyst, who can model in the existing standard, must not need to learn new concepts in order to apply the standard elements in the model and notation.* Although the CoMoNo concept enriches the standard BPMN Conversation Diagram with additional characteristics, it does not change the behaviour of the elements, which were derived from the standard. Without any change in handling, a CoMoNo Diagram can be used exactly as a BPMN Conversation Diagram. Only the modelling of the additional characteristics deviates from the standard.

R11 - Clear Visual Language: *More than 50% of users must consider the visual language easy to understand and the readability of the symbols must not be altered by a black and white print.* The CoMoNo notation only relies on black-and-white icon-graphics that do not use gradients. Using such simple graphics ensures backwards compatibility with older printers or other printing techniques. The understandability of the graphics is validated in Chapter 5.

4.5 Conclusion

The CoMoNo concept defines three modules that build on top each other: modelling, analysis, and planning. The modelling module provides a meta-model for an enhanced communication model and the according notation. The analysis module defines methods based on the modelling module: The analysis of communication media and the analysis of the modelled communication requirements of business processes. Building on top of all this, the planning modules describes two methods to propose changes to the communication infrastructure: The planning of a clean-slate communication architecture and the planning of an architecture that extends an existing one.

This concept stands on the shoulders of media selection theories and business process modelling. The following two paragraphs will position it in those two contexts.

The classifications sender and receiver as well as the basic characteristic directionality already date back to the basic communication model introduced by Shannon [Sha48a]. The Media Richness Theory developed by Daft and Lengel introduced feedback, channel, and language. While the former is related to the characteristics synchronicity and reception, the latter two are present in the content types of the CoMoNo concept [DL84; DL86; DLT87]. The characteristic reprocessability is directly related to its counterpart proposed by the Media Synchronicity Theory. Moreover, the content types are related to the symbol sets property of media synchronicity [Den+98; DV99; DFV08]. Task-Technology Fit Theory introduces concepts like simultaneous input, anonymity, and group display as part of the communication support perspective, which are reflected in the characteristics editor multiplicity, and visibility [ZB98; ZK08]. Finally, the essential aspects

	Sha	MRT	MST	TTF	W20
Synchronicity		X	X		
Directionality	X	X			
Reception		X			
Visibility				X	X
Reprocessability			X		X
Content type		X	X		
Multiplicity	X			X	X
Distance	X				
Sha: Shannon, MRT: Media Richness Theory, MST: Media Synchronicity Theory, TTF: Task-Technology Fit, W20: Web 2.0					

Table 4.3: Theory impact on characteristics.

search and authoring of the Enterprise 2.0 SLATES paradigm underline the importance of characteristics like reprocessability, visibility, and editor multiplicity [McA06]. Table 4.3 highlights the influences of the different theories on the characteristics.

Regarding the "process perspective" of the BPM taxonomy introduced by Giaglis, the CoMoNo concept covers the aspects "organizational" (who is taking part in a conversation), "behavioural" (how does the conversation take place), and "functional" (what kind information is exchanged). Regarding the "objectives perspective" it covers the aspects "understanding & communication" (a common model and notation to describe conversations) and "process improvement" (analysis and planning procedures to identify improvement potentials) [Gia01]. The model, notation, and analysis procedures proposed by the concept take place during the "diagnosis" phase of the BPM lifecycle introduced by van der Aalst and van Hee. The "redesign" life phase is reflected by the planning procedure for add-on communication media [AH04]. The "graphical standard" classification proposed by Ko et al. clearly fits the notation aspect of the

CoMoNo concept, while the detailed communication characteristics could be considered a “diagnosis standard” in their sense [KLL09].

As was shown in the previous section, the CoMoNo concept offers solutions for all defined requirements. How well an actual implementation of the concept performs in a realistic scenario is evaluated in the following chapter, which describes a prototype based on this concept and its application to a case study within the CRC 666.

Chapter 5

Prototype & Case Study

This chapter describes a prototypical implementation of the previously introduced CoMoNo concept and its application in a case study at the CRC 666. In the first section, the characteristics of the relevant communication media are evaluated regarding their ability to distinguish the individual media from each other. The second section introduces the prototypical implementation of a modelling tool for CoMoNo models and a graphical analysis and planning tool. The models are presented following the notation defined in the previous chapter. The third section describes the application of the CoMoNo concept in the case study. During the case study, interviews were conducted using the modelling tool in order to identify the characteristics of the communication processes at the CRC 666. Prototypical implementations of the analysis and planning procedures defined by the CoMoNo concept were applied to the results gathered during the interviews. Finally, the findings of the analysis and the potential improvements identified during the planning are evaluated.

5.1 Analysis of Characteristics

The characteristics of communication media defined in Table 5.1 and explained in Appendix B are evaluated regarding Requirement R1 by calculating their cross simple matching similarity. In order to fulfil the fit-criterion of the requirement, the presented characteristics need to "clearly differentiate the available communication media", i.e. no two communication media should have perfectly similar characteristics.

In order to compare all media to each other, the statistical automation software RapidMiner, originally developed at the Dortmund University of Technology, was used. The simple matching similarity as applied by RapidMiner [Rap11] is defined as the number of similarities between the characteristics of two communication media in relation to their total number of characteristics. It is closely related to the simple matching coefficient, which is defined as [Rom04]: $C_{j,k} = \frac{a+d}{a+b+c+d} \quad 0.0 \leq C_{j,k} \leq 1.0$

Comparing the two items j and k, a denotes the sum of attributes present in both, d denotes the sum of attributes missing in both, while b and c denote the sum of attributes only present in one. Generalising the above coefficient, the simple matching similarity is defined as: $SMS_{j,k} = \frac{s}{t} \quad 0.0 \leq SMS_{j,k} \leq 1.0$ Here s denotes the sum of identical attributes present in both and t denotes the total number of attributes.

Calculating the similarity of every possible pair of communication media shows, that regarding the proposed characteristics, no two communication media are identical (see Figure 5.2) which validates the fit criterion of requirement R1.

Medium	Synchronicity	Directionality	Reception	Visibility	Reprocessability	Editor Multiplicity	Participant Multiplicity	Distance	Content
Face to Face	s	b	e	O,P	t	1	2	1000	Au,Gr,Ph,Ta,Te,Vi
Group Meeting	s	b	e	P,G	r	10	50	1000	Au,Gr,Ph,Ta,Te,Vi
Presentation	s	u	e	P	t	10	250	1000	Au,Gr,Ph,Ta,Te,Vi
Telephone	s	b	e	O,P	t	1	2	100000000	Au
Phone Conference	s	b	e	P	t	10	250	100000000	Au
Video Conference	s	b	e	P	t	10	250	100000000	Au,Gr,Ta,Te,Vi
SMS	a	ub	ie	P	r	1	10	100000000	Te
Letter	a	ub	ie	P	r	1	50	100000000	Gr,Ta,Te
Fax	a	ub	e	G	r	1	50	100000000	Gr,Ta,Te
Email	a	b	ie	P	r	1	50	100000000	Fi,Gr,Ta,Te
Email Newsletter	a	u	i	P,G	r	1	1500000	100000000	Fi,Gr,Ta,Te
Email Mailinglist	a	b	i	P,G	r	1	250	100000000	Fi,Gr,Ta,Te
Publication	a	u	i	W	r	10	1000000000	100000000	Gr,Ta,Te
Blog	a	ub	i	G,W	r	1	10000000	100000000	Au,Fi,Gr,Ta,Te,Vi
Wiki	a	b	i	G,W	r	50	10000000	100000000	Fi,Gr,Ta,Te
Collab. Writing	as	b	ie	P,G	r	50	250	100000000	Gr,Ta,Te
DSS	a	b	i	O,P,G	r	250	250	100000000	Da,De,Te
Shared Drive	a	ub	i	P,G	r	1	250	100000000	Fi
DMS	a	ub	ie	P,G	r	1	1500000	100000000	De,Fi,Gr,Ta,Te
u: uni-directional, b: bi-directional; s: synchronous, a: asynchronous; O:OTR, P:private, G:group, W:world; r:reprocessable, t:transient; e:explicit, i: implicit; Au: audio, Da: date, De: decision, Fi: file, Gr: graphic, Ph: physical, SD: struct. data, Ta: table, Te: text, Vi: video									

Table 5.1: Communication media characteristics

	Wiki	Video Conference	Telephone	Shared Drive	SMS	Publication	Presentation	Phone Conference	Letter	Group Meeting	Fax	Face to Face	Email Newsletter	Email Mailinglist	Email	DSS	DMS	Collab. Writing	Blog
Blog	0.67	0.11	0.22	0.67	0.56	0.44	0.00	0.11	0.56	0.11	0.56	0.11	0.56	0.56	0.44	0.44	0.56	0.22	1.00
Collab. Writing	0.44	0.33	0.22	0.44	0.33	0.33	0.11	0.33	0.44	0.33	0.33	0.11	0.33	0.56	0.44	0.44	0.44	1.00	
DMS	0.33	0.11	0.22	0.67	0.67	0.33	0.00	0.11	0.67	0.22	0.56	0.11	0.67	0.56	0.56	0.33	1.00		
DSS	0.56	0.33	0.22	0.56	0.33	0.44	0.11	0.33	0.33	0.22	0.33	0.11	0.44	0.67	0.44	1.00			
Email	0.56	0.33	0.33	0.44	0.67	0.33	0.11	0.33	0.78	0.33	0.56	0.22	0.56	0.67	1.00				
Email Mailinglist	0.67	0.33	0.33	0.78	0.44	0.44	0.11	0.33	0.44	0.33	0.44	0.22	0.78	1.00					
Email Newsletter	0.56	0.11	0.22	0.67	0.44	0.56	0.11	0.11	0.44	0.22	0.44	0.11	1.00						
Face to Face	0.11	0.44	0.78	0.11	0.11	0.00	0.56	0.44	0.11	0.56	0.22	1.00							
Fax	0.33	0.22	0.33	0.56	0.56	0.44	0.11	0.22	0.78	0.33	1.00								
Group Meeting	0.22	0.44	0.33	0.22	0.11	0.11	0.56	0.44	0.22	1.00									
Letter	0.33	0.22	0.22	0.56	0.78	0.44	0.11	0.22	1.00										
Phone Conference	0.22	0.89	0.67	0.22	0.22	0.11	0.67	1.00											
Presentation	0.00	0.67	0.33	0.11	0.11	0.11	1.00												
Publication	0.44	0.11	0.11	0.44	0.33	1.00													
SMS	0.33	0.22	0.22	0.56	1.00														
Shared Drive	0.44	0.22	0.22	1.00															
Telephone	0.22	0.56	1.00																
Video Conference	0.22	1.00																	
Wiki	1.00																		

Table 5.2: Communication media simple matching similarities

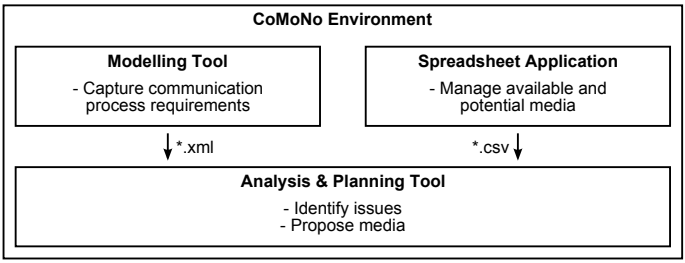

Figure 5.1: CoMoNo environment overview

5.2 CoMoNo Environment

The CoMoNo environment consists of three applications: A modelling tool enabling the creation of CoMoNo models representing the communication processes and their characteristics, a standard spreadsheet application supporting the management of available and potential communication media, and the analysis and planning tool, which implements the procedures described in Chapter 4 (see Figure 5.1). Any spreadsheet application supporting comma separated values (*.csv) is sufficient to manage the media. The following sections describe the implementation of the modelling tool and the analysis and planning tool.

5.2.1 Modelling Tool

In order to test the communication model notation (requirement R4), and its appearance (requirement R11), a prototypical implementation of a modelling tool is necessary. Two modelling tools were analysed regarding their adaptability: “Yaoqiang BPMN Editor” and “ARIS Business Architect”.

Yaoqiang BPMN Editor is a graphical environment targeted at the

editing of BPMN 2.0 compliant business process diagrams [Yao12]. It is developed as an open source project and has a rich set of features including real-time BPMN syntax validation, version control, process simulation, and various import and export interfaces. Even though it is possible to add functionality via the provided plug-in architecture or to adapt the full source-code, this approach would result in a highly complex adoption in order to integrate the CoMoNo concept into Yaoqiang BPMN Editor.

ARIS Business Architect on the other hand is a commercial, closed source product by Software AG [Sof12a]. It is an integral part of the product landscape provided by Software AG and is based on a server/client architecture. All models and objects are stored in a central ARIS repository, which also facilitates the locking, versioning, and change management of all stored elements. On top of this, the client provides analysis of models, report generation, and searching stored models and objects. Both, the server and the client are designed to be highly customisable. Using the administrative interface of the client, it is possible to extend the existing model types with additional objects and attributes.

Because of its simple customisation, the ARIS Business Architect became the basis for the prototypical implementation of a CoMoNo modelling tool, which the following sections describe.

Overview User Interface

The user interface of the CoMoNo modelling tool is sectioned into four major areas, which are highlighted in 5.2. The navigation area (1) allows the user to browse the available ARIS repositories and their subfolders for CoMoNo models and the associated objects. The area

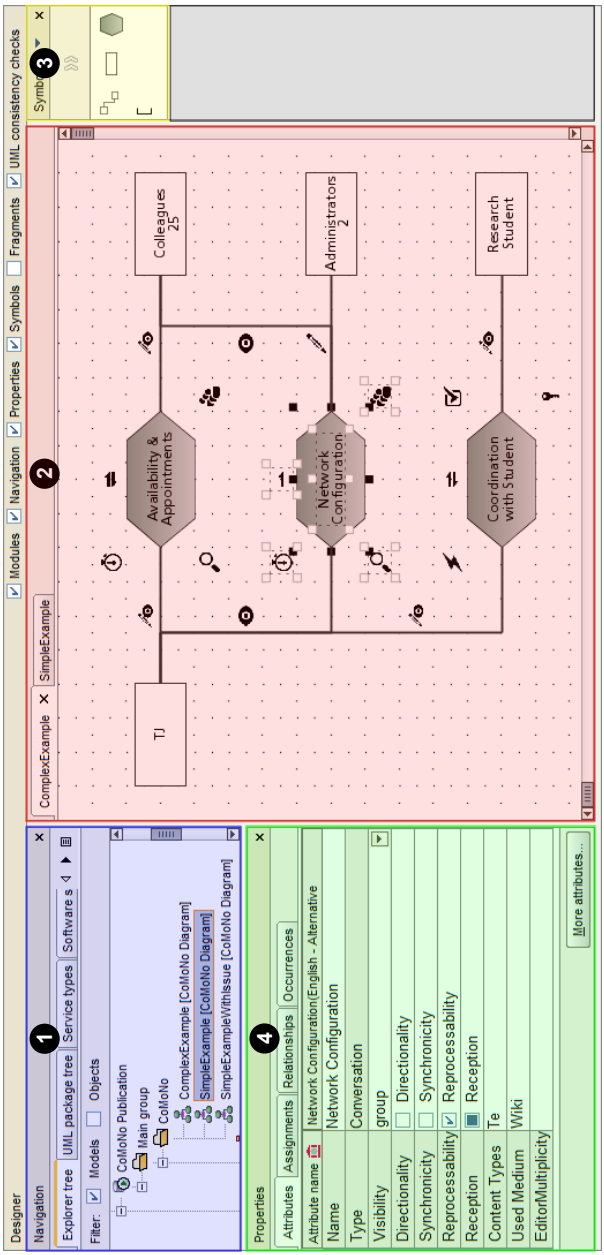

Figure 5.2: Overview of the modelling tool

also provides access to the change management and versioning functions provided by the ARIS infrastructure. Once the user opens a model using the navigation, it becomes available in the central editor area of the tool (2). In the editor, the user can create and manipulate the CoMoNo model elements described in Section 4.1.1. The editor offers common modelling features such as moving, resizing, aligning, grid-snapping, or even automated arranging of entities, as well as creating connections. While the creation of new entities in the editor is based on a right-click mouse menu, the symbols area on the right (3) provides quick access to all CoMoNo entities. Once the user selects an entity or connection, its properties are shown in the dialogue to the bottom left (4). Here the user can manipulate the CoMoNo characteristics. Any change is directly reflected in the central editor view by a change of the according presentation.

The configuration of an ARIS repository is split into two main sections: the method and the conventions. The method defines all entities that can be used to create a model: model types, object types, symbols, connection types, attribute types, attribute type groups, and attribute symbols.

Model types define what kind of models can be created. Custom model types have to be derived from predefined ones.

Object types specify which objects are generally available in models. ARIS does not allow the creation of new object types, but existing ones can be renamed.

The symbols are the presentation of the object types. They define how the object types are graphically shown. The ARIS framework includes a symbol editor, which supports the manipulation of custom symbols.

Connection types determine what kinds of connections are available and which object types can be connected by them. Similar to the object types, ARIS only allows the renaming of existing connection types.

The properties of object types as well as connection types are specified by the attribute types. Opposed to the object and connection types, attribute types can be created from scratch. They can be organised using the attribute types groups and they can use the attribute symbols for their presentation. Possible data types of attributes are: multi-line text, boolean, pre-defined values, integer, floating-point number, date, time, and point in time.

The following paragraphs only cover the CoMoNo specific customisation steps, the standard procedures involved in customising and maintaining an ARIS repository are described in the technical manual [Sof12b].

CoMoNo Attribute Types

The definition of the new attribute types representing the CoMoNo characteristics occurs in three steps, first the definition of a new attribute type group *CoMoNo* as a subgroup of the *BPMN 2.0* group, second the definition of the new attribute symbols, and last the definition of the attributes themselves.

In order to be able to use the custom symbols described in Section 4.1.2, they have to be converted to the ARIS format using the symbol editor. Once this is done, a new symbol can be derived from a predefined one. As the predefined symbol has an impact on the size and appearance of the new symbol, all new symbols should use the same predefined symbol as their basis. Using the new attribute type

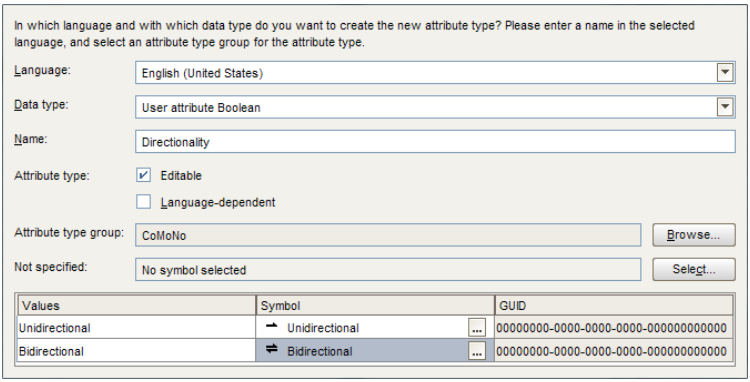

Figure 5.3: ARIS attribute dialogue

group *CoMoNo* and the custom attribute symbols, the new attribute types can be defined using the dialogue shown in Figure 5.3 The characteristics directionality, synchronicity, reception, and reprocessability are modelled as boolean attributes, while visibility, role, and position are modelled as pre-defined values attributes. The location and the required content types are modelled as string attributes and the multiplicities are represented by numeric attributes.

CoMoNo Model Type and Conventions

As the CoMoNo concept is closely related to the BPMN 2.0 Conversation Diagram, the *CoMoNo Diagram* is derived from the predefined conversation diagram type. Following this step, a new method filter for the new type of diagram is created using the *Filter Wizard*. During the wizard, the name and definition of the new filter need to be given. It also queries which model type should be used and which object and connection types defined by the model type are to be adapted. The most important aspect of the wizard is the selection of the newly

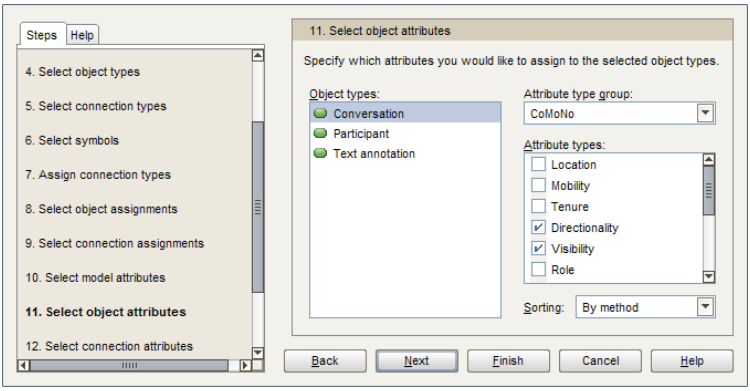

Figure 5.4: ARIS filter wizard

defined attribute types and their association to the respective object or connection types (see Figure 5.4).

In order to define the positioning of the new attribute types, a new *CoMoNo* template needs to be defined. Again, a wizard guides through the definition process. First, the new template needs to be named and a method filter to be used needs to be selected. In the subsequent steps, the new attribute symbols are placed relative to the object symbols and connections.

Based on the above customisations, a new CoMoNo model can now be created by logging into an accordingly configured ARIS repository and selecting the new CoMoNo filter when opening a database.

5.2.2 Analysis and Planning Tool

The analysis and planning tool implements the procedures defined in Chapter 4. The graphical interface consist of three areas, one for loading and reviewing the conversations defined in the CoMoNo model provided by the modelling tool, one for loading and selecting the

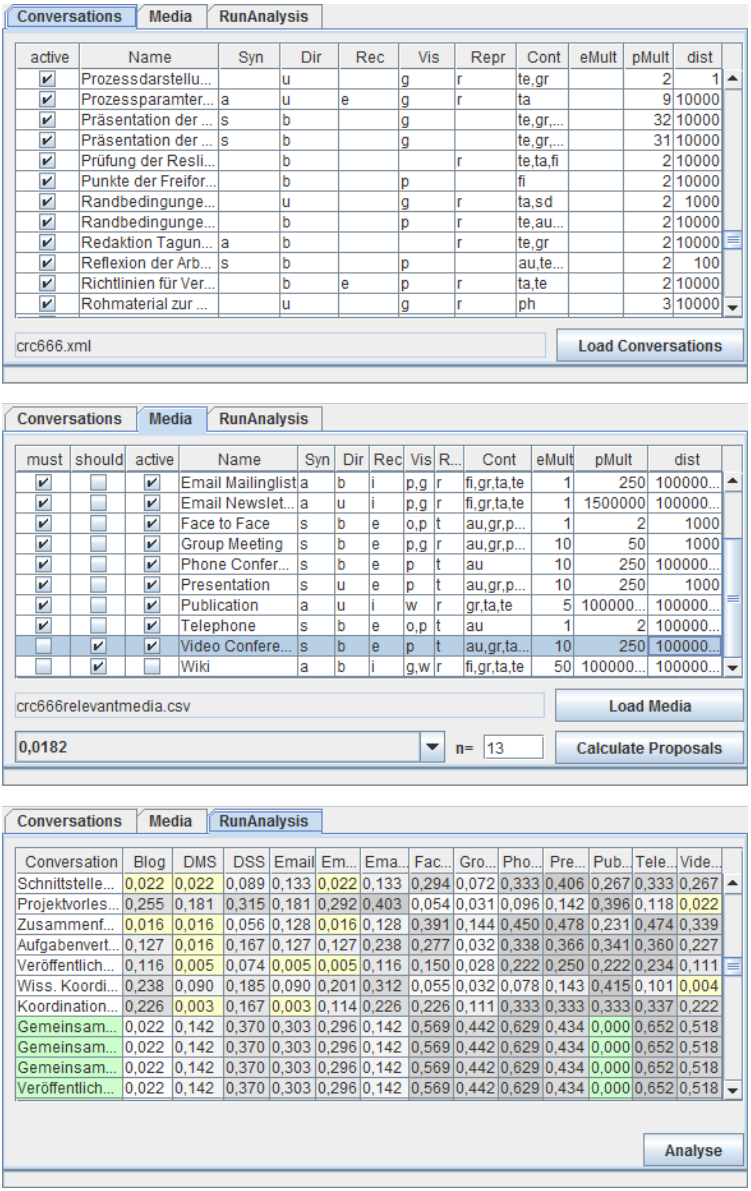

Figure 5.5: CoMoNo analysis and planning tool

communication media, and one for the analysis of the combination of selected conversations and media (see Figure 5.5).

The conversations area allows the user to select a *.xml file provided by the modelling tool. The interface then loads and lists all conversations, which were parsed from the file with all their specified requirements. The user can deselect individual conversations, which are subsequently ignored.

Aside the loading of a list of media to be used, the media area also supports the manual or automatic selection of media to be considered for the following analysis. Manual selection is simply done through activating or deactivating individual media. For an automated proposal, the user needs to select which media must be used and which should be used. Selecting the current media as mandatory reflects the "add-on proposal" use case; not selecting any mandatory media reflects the "clean-slate proposal" use case. After setting the overall number of media to be selected, the tool can automatically generate proposals, which are listed according to their ranking. Selecting a proposal automatically activates the according media in the listing.

The analysis area uses the activated conversations and media from the previous steps in order to identify issues. The interface lists the dissimilarity coefficient $d_{C,M}$ for each conversation/medium combination. Conversations for which media without issues can be found are highlighted in green, as are the specific matches. For those conversations without ideal match, the match with the lowest dissimilarity coefficient is highlighted in yellow. The overall list shows the conversations with the strongest discrepancies first.

5.3 Case Study

In order to examine how the CoMoNo concept performs when applied to a real scenario, a case study was conducted at the CRC 666. The focus of the case study was to support the validation (see Section 4.4) of the CoMoNo concept regarding the requirements R4 “Communication Model Notation”, R6 “Identify Issues”, R8 “Clean-Slate Proposal”, R9 “Add-On Proposal”, and R11 “Clear Visual Language” (Chapter 3). The analysis and planning procedures described in Section 4.2.2 and Section 4.3 were implemented in Java, which enabled automated execution of the procedures based on the XML data provided by the CoMoNo modelling tool.

5.3.1 CoMoNo Interviews

The goal of the interviews was to gather communication requirement models in order to validate the methods for issue identification, clean-slate proposal, and add-on proposal based on realistic input data. As the interviews involved creating a CoMoNo diagram together with the interviewee, they were later on asked about their impressions of the model.

The structure of the interview guideline A.1 follows the suggestions of Mayer and structures the interview into six generic sections [May09]: the interviewee, communication partners, communication contents, communication requirements, available media, and past communication issues. At the beginning of each interview, the participant was briefly introduced to the concept and the notation. Template A.2 provides an overview of the symbols and the communication characteristics and was a useful accessory for the interviewer and

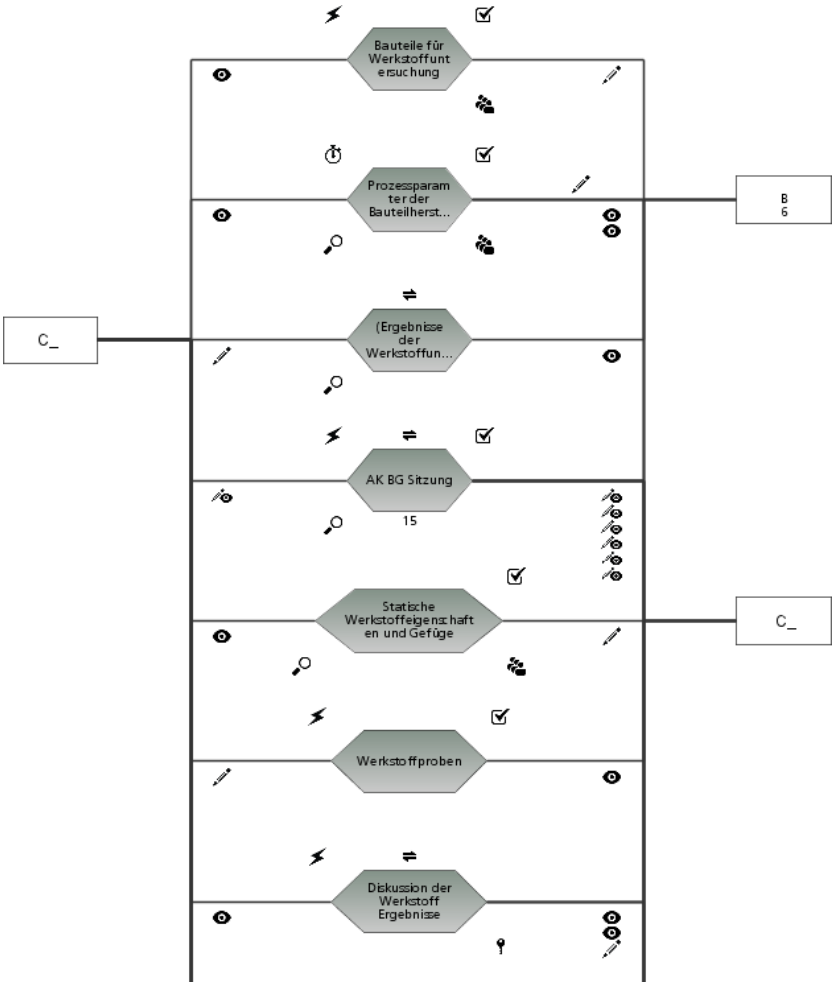

Figure 5.6: Partial CoMoNo model of an interview

the participant. It was made clear, that only current and foreseeable communication relevant to the CRC 666 was the objective of this interview.

During the first interview, the model prepared with a participant representing the interviewee with his characteristics location and position. Beginning from this initial set-up, the interviewee was first asked with whom he exchanged information about what topic. This conversation was then completed with all relevant requirements after which the interview proceeded to the next conversation and possibly to the next new participant.

In the second interview, this procedure was changed. Now all potential communication partners were covered first, then all communication topics, and finally the communication requirements for each conversation. By first capturing all structural information followed by the details, the process became clearer and easier to conduct. Compared to the first interview, there was less need to switch between the three basic perspectives: with whom, about what, with which requirements. Thus, the procedure was maintained during the subsequent interviews. An example of a CoMoNo model created during an interview can be seen in Figure 5.6.

After each interview, each interviewee was asked regarding his agreement to the following two questions: “The created diagram was helpful for the interview procedure.” (German: “Das erstellte Diagramm war bei der Durchführung des Interviews hilfreich.”) “The presentation of the diagram is easy to understand.” (German: “Die Darstellung des Diagramms ist gut verständlich.”)

Each statement was rated as a five-level Likert item [Lik32] with the levels “disagree”, “somewhat disagree”, “neutral”, “somewhat

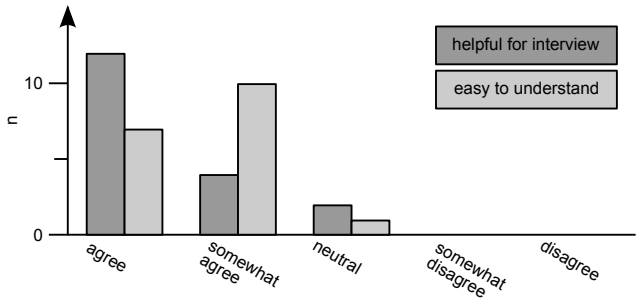

Figure 5.7: Distribution of questionnaire replies

agree", "agree" (German: "trifft nicht zu", "trifft eher nicht zu", "neutral", "trifft eher zu", "trifft zu").

As shown in Figure 5.7, 12 interviewees agreed, 4 somewhat agreed, and 2 were neutral regarding the helpfulness of the diagram during the interview. Overall 16 of 18 interviewees showed a positive attitude. 7 interviewees agreed that the notation was easy to understand, 10 somewhat agreed, and 1 stayed neutral. In summary 17 of 18 interviewees showed a positive inclination regarding the notation.

5.3.2 Analysis of Interview Data

Using the ARIS foundation of the CoMoNo modelling tool, the gathered models could be exported as XML files, which enabled the seamless analysis of the gathered data. It was possible to export either individual interviews or the whole collection at once. Based on the listing of all conversations ($n = 351$) with their aggregated multiplicities and calculated distances, the occurrence of the individual characteristics expressions was analysed (see Figure 5.8).

Of the 351 modelled conversations, 96 require synchronous communication. With 82 conversations, roughly the same proportion re-

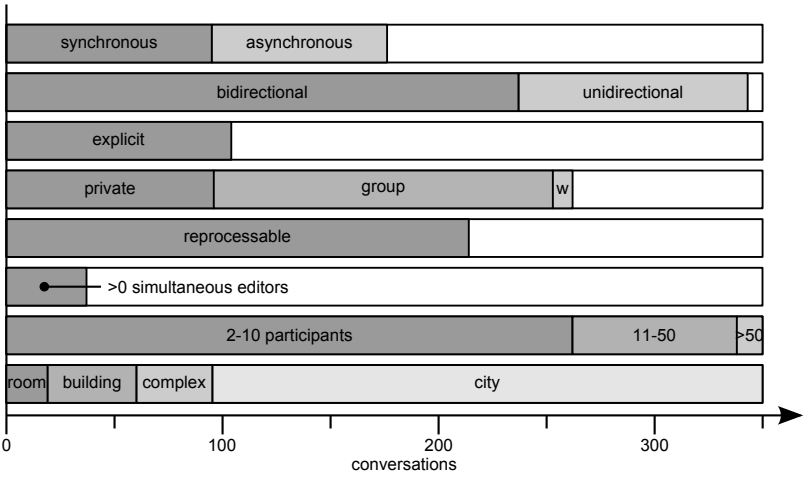

Figure 5.8: Distribution of the individual characteristics

quires asynchronous communication. Almost half the conversations did not specify this requirement because the interviewee considered both adequate. The rather abstract nature of this characteristic could also be relevant to its low number of occurrences. Interviewees often considered synchronous communication necessary, where ambiguous information needed clarification, especially when communicating between different scientific disciplines. Asynchronous communication was usually preferred where not additional clarification was expected.

238 conversations required bidirectional communication, while only 107 provided information in a unidirectional manner. Unidirectional communication was usually chosen in situations where generally understandable information was provided and no clarification was deemed necessary. The high proportion of bidirectional communication seems appropriate for a research centre dealing with novel

technologies from many domains.

Explicit confirmation of the received information was only considered necessary in 105 conversations. Many interviewees regard implicit confirmation as sufficient: If an expected reply is not received after a given period of time, they simply inquire again. Moreover, some interviewees considered requiring explicit confirmation as intrusive and impolite.

The interviewees reported 10 conversations specifically visible to the general public. As pretty much all scientists of the research centre are actively publishing, this number can safely be assumed somewhat higher. 158 conversations were explicitly specified as group visible and just 97 conversations were considered private. In most cases of private conversations, the interviewees wanted to avoid confusion about preliminary information. In only very few situations interviewees wanted to keep information permanently protected. The off-the-record requirement was only applied in 2 conversations. Given the nature of this characteristic, many off-the-record conversations were probably not mentioned during the interviews. Overall 252 of 351 conversations were not considered private and the majority of the 97 private conversations would be available in a curated form. This open conversational style should be considered a positive sign of the scientific exchange in the research centre.

With 215 conversations, the majority of reported information exchanges required reprocessability. Some interviewees reported that the same information was queried multiple times by the same or different participants. Having this information available in a reprocessable form, would reduce the communication load on the information providers.

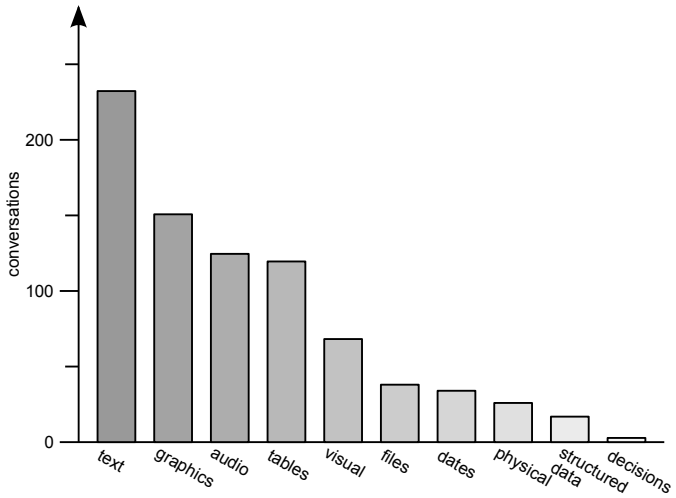

Figure 5.9: Distribution of content types

Only 38 conversations were reported to require simultaneous editing by multiple senders. Of these 15 fell into the group of 1-10 editors, 12 required 11-20 editors, and another 12 required more than 20 editors. The interviewees considered the collaborative editing of scientific papers as well as the writing of the aggregated progress reports of the research centre. In addition, some discursive conversations required simultaneous provision of information.

With 264 conversations, the majority was reported to take place between 2-10 participants. 77 conversations involved 11-50 participants, and 10 conversations involved more than 50 participants. The latter also coincided with the 10 conversations specifically targeted at the general public.

With 253 conversations, the majority of exchanges involved participants from different locations in the same city. 36 conversations

took place within the same complex, 42 within the same building, and 20 conversations took place between participants in the same room.

As each conversation can involve multiple forms of content, the sum of the recorded occurrences is larger than the overall number of conversations. As shown in Figure 5.9, the five most common forms of content are textual (232), graphical (151), audio (125), tabular (120), and visual (69).

In summary, the communication at the CRC 666 is characterised by a mix of synchronous and asynchronous conversations, most of which are bidirectional. Only few conversations need explicit confirmation or simultaneous editing but many need to be reprocessable later. The majority of conversations occurs openly within the research centre between a small number (≤ 10) of participants. Only 98 conversations take place within walking distance of all participants. While many conversations require audio/visual exchange of information, the dominant representations are text, graphics, and tables.

5.3.3 Analysis of Communication Issues

In order to identify mismatches between communication capabilities and requirements, a list of communication media available to the members of the research centre was compiled:

- Face to Face
- Group Meeting
- Presentation
- Scientific Publication
- Telephone
- Telephone Conferencing
- Email, Mailinglist, Newsletter

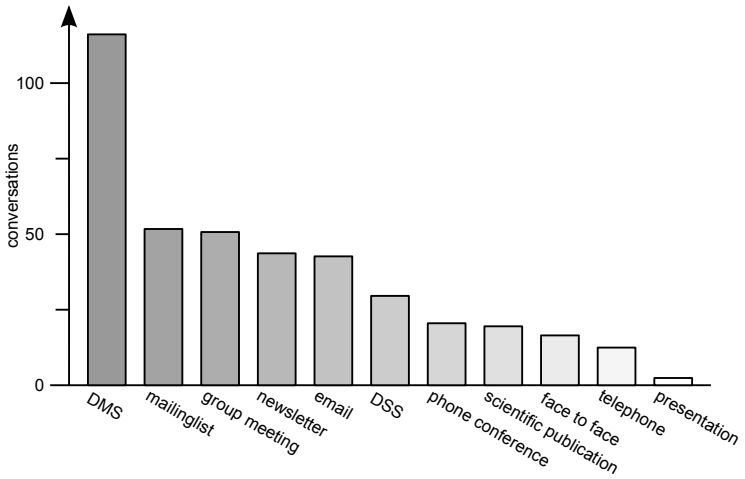

Figure 5.10: Distribution of media matches

- Document Management System
- Decision Support System

The list of conversations gathered during the interviews was then matched to the capabilities of the available media using the dissimilarity coefficient introduced in Section 4.1.3. 19 of the 351 conversations had a dissimilarity coefficient $d_{C,M} \geq \frac{1}{9}$ (see Table 5.3). 155 showed minor issues with a coefficient $0.0 < d_{C,M} \leq \frac{1}{9}$ which could only result from an incomplete mismatch between one of the multiplicities, the distance, and the required content types. For more than half of the conversations (177) at least one matching medium with a coefficient $d_{C,M} = 0$ could be found. Figure 5.10 shows how often each available medium matched with a potential conversation. The average dissimilarity coefficient across all conversations matched with the available media is $d_{C,M} = 0.0233$.

ID	Conversation	Proposed Medium	Unmatched	Manual Medium	Comment
239	Handover of samples	Group Meeting	unidir., city		Unidirectional is not a hard requirement in this context. Travelling acceptable for physical exchange.
064	Handover of samples	Group Meeting	unidir., city		“
331	Handover of samples	Group Meeting	unidir., city		“
274	Simulation model	DMS	structured data		The information will have to be stored as a file.
113	Requirements	DMS	structured data		“
292	Coordination of dates	DSS	explicit		Send the doodle link via email and activate explicit reception.
291	Coordination of dates	DSS	explicit		“
298,301	Coordination of dates	DSS	explicit		Verify using a second channel.
329	Handover of samples	DMS	physical	Physical storage	A storage location accessible to the group for asynchronous exchange of parts.
264	Handover of material	DMS	physical		“
082	Analysis of samples	DMS	synchronous	Face to face	A brief report should be made available to the group. Travelling not avoidable without video conference.
039	Task delegation	Group Meeting	unidirectional		Unidirectional is not a hard requirement in this context.
337	Handover of samples	Group Meeting	unidirectional		“
185	Coordination of proposal	Group Meeting	asynchronous	Email	With a coordinated process, email can be used.
289	Coordination of dates	Phone Conference	date		Verbally agree on a date. Does it have to be synchronous?
287	Announcement of dates	Email Newsletter	date		Textually represent the date in the email.
303	Announcement of dates	Email Newsletter	date		“
175	Integration of functions	DMS	synchronous	Face to face	A brief report should be made available to the group.

Table 5.3: Suggested matches for conversations with $d_{C,M} > \frac{1}{9}$

Aside this algorithmic analysis for communication issues, the models created during the interviews also contained 34 manually reported issues. 8 of these revolved around files being too large for e-mail or the necessity of a central repository for files. 8 more issues reported problems related to incompatible software formats or operating systems. 6 reflected social aspects such as different priorisations of tasks or the lack of responsiveness. Another 6 reported misunderstandings which stem from the complex interdisciplinary glossary and a lack of visibility of the other sub-projects current status. The remaining 6 related to diverse aspects like the current state of the experimental facilities, the lack of synchronous editing of documents, or the visibility of unpublished publications.

5.3.4 Clean-Slate Proposal

For the clean-slate proposal, a list of potential communication media and a desired number of media was provided. The list of media contained the ones listed in Table 5.1 with letter, fax system, shared drive, and collaborative writing being left out. The former two were not considered relevant for internal communication, and a shared drive would not work across the independent networks within the CRC 666. Collaborative writing is currently only available as software as a service provided by third parties. The automated planning tool used these two inputs to deliver a ranked list of potential media. The top candidates for a range of media combinations are:

1: DMS (avg. $d_{C,M1} = 0.0843$)
2: DMS, group meeting (avg. $d_{C,M2} = 0.0344$)
3: Blog, DMS, group meeting (avg. $d_{C,M3} = 0.0288$)
4: Blog, DMS, DSS, group meeting (avg. $d_{C,M4} = 0.0259$)

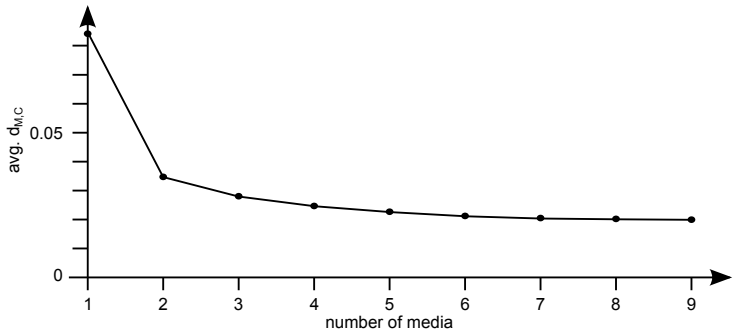

Figure 5.11: Number of media vs. avg. $d_{C,M}$

5: DSS, blog, video conference, DMS, group meeting
(avg. $d_{C,M5} = 0.0232$)

6: DSS, presentation, blog, video conference, DMS, group meeting
(avg. $d_{C,M6} = 0.0212$)

7: DSS, presentation, blog, video conference, DMS, publication, group meeting(avg. $d_{C,M7} = 0.0205$)

8: DSS, presentation, blog, telephone/face to face, video conference, DMS, publication, group meeting (avg. $d_{C,M8} = 0.0202$)

9: DSS, wiki, presentation, blog, telephone/face to Face, video conference, DMS, publication, group meeting
(avg. $d_{C,M9} = 0.0201$)

Figure 5.11 shows the development of the average sum of dissimilarities for the best-ranked set of communication media in regard to the number of media in the set. It provided a good guide regarding how many media are actually helpful and showed that the more media are already available, the lower the impact of additional media would be. The residual conversations with issues are not solvable by currently available media. As these issues could not be dealt with by

appropriate media choice, they needed to be analysed individually in order to identify countermeasures.

The analysis of the clean-slate proposal revealed that it could easily outperform the present selection of media at the research centre. Already five matched media offer an equivalent rating: $d_{C,M5} = 0.0232 < 0.0233$. The selected five media reduced the number of low-mismatch conversations ($d_{C,M} < \frac{1}{9}$) by 33 while increasing the number of conversations with stronger mismatches ($d_{C,M} \geq \frac{1}{9}$) by 8.

5.3.5 Add-On Proposal

The analysis of add-on proposals examined how the communication at the CRC 666 could benefit from additional communication media. Potential candidates were blog, wiki, and a video conference solution. Out of these three, the blog improved the average dissimilarity coefficient the most ($d_{C,M_{blog}} = 0.0213 < 0.0233$), the video conference came second ($d_{C,M_{video}} = 0.0223 < 0.0233$), and the wiki provided hardly any benefit ($d_{C,M_{wiki}} = 0.0232 < 0.0233$). The gains of blog and video conference were complementary, as the gain of both applied together ($d_{C,M_{blog,video}} = 0.0203$) was about equal to the sum of the individual gains.

Neither blog nor video conferencing could reduce the number of conversations with $d_{C,M} >= \frac{1}{9}$ but both reduced the number of conversations with minor mismatches: Blog down to 139 from 155, video to 143, and both together to 127. This shows that the addition of each solved different communication issues.

Blogging about the current status of ones work would increase the overall awareness of the current state even in unrelated sub-projects. It would mainly be used in contexts where the recipient of a piece of

information is not clearly specified but the sender assumes it could be of interest to some colleagues.

Video conferencing, especially desktop solutions that are often available with shared interactive whiteboards, would target conversations where the partner is well known but in a location which is not quickly reachable. It would facilitate the spontaneous exchange of visual information, which is often relevant where physical samples are used, even when the participants are not located nearby.

Even though there are currently no convincing collaborative writing solutions which would enable the synchronous editing of documents with multiple participants available, this option was analysed as well in order to understand its potential impact. With a dissimilarity coefficient of $d_{C,M_{writing}} = 0.0213$ its gains would be comparable to those of blogging.

5.4 Validation

This section will evaluate the results of the application of the CoMoNo concept in the case study regarding the requirements stated in Chapter 3. As requirement R3 and R10 are not implementation specific, they are considered validated in Chapter 4 Section 4.4.

R1 - Communication Media and Process Characteristics: *The defined characteristics must be fine-grained enough in order to clearly differentiate the communication media available in a product development context.* The analysis of the characteristics showed that no two communication media are identical in regard to the simple matching similarity (see Table 5.2), thus the characteristics allow the clear differentiation of the media.

R2 - Dissimilarity Coefficient for Characteristics: *All characteristics shared between process and medium are taken into account in order to calculate the dissimilarity coefficient. Using the coefficient, it must be possible to rank a given list of communication process and communication media combinations.* The application of the dissimilarity coefficient to realistic communication process and media combinations in the analysis and planning procedures showed comprehensible results. While there were a few unreasonable suggestions like using a document management system or a mailing list for a physical exchange, these were identified as having issues. The majority of automated matches were reasonable. For example the conversations ID197-200 (meetings of the steering committee) and ID202-205 (meetings of all researchers) best matched with the medium "group meeting" while the conversations ID145-149, ID316-320 (scientific publications) were correctly matched with the medium "publication". Also conversation ID141 (gossip) was correctly matched with face to face or telephone as medium, as it required off-the-record capability.

R4 - Communication Model Notation: *A visual notation for the central elements and characteristics of the communication model must be provided. More than 50% of users must consider the visual notation helpful during the interview.* 94% of the interviewees supported the statement "The created diagram was helpful for the interview procedure.". Of these, 39% fully agreed. Also from the perspective of the analysts, the visual notation is clearly a valuable asset, supporting the modelling process as well as the exchange and discussion of findings.

R5 - Track Deployed Communication Media: *A way to track the communication media available to the users of the organisation and their characteristics must be provided.* The management of the deployed communication media in a spreadsheet application is an appropriate solution.

R6 - Identify Issues: *It must be possible to identify issues and bottlenecks based on a specific communication model enriched with advanced characteristics and the information about the currently available communication media.* The analysis of communication issues provided in Section 5.3.3 revealed 164 conversations for which no perfectly matching medium could be found, 16 of these with a dissimilarity coefficient $d_{C,M} \geq \frac{1}{9}$. Some could be circumvented by manually proposing a different medium with fewer drawbacks; other issues could be resolved by adapting the communication processes to the given media (see Table 5.3). The majority of the 164 issues were caused by minor content type or distance deviations, which are considered typical for a context in which the participants are spread out across a city but need to exchange or review physical objects. These results show that the analysis method proposed by the CoMoNo concept supports the identification of communication issues.

R7 - Track Potential Communication Media: *A way to track potential communication media and their characteristics must be provided.* The potential communication media were managed in a common spreadsheet application. This provided an appropriate solution.

R8 - Propose Clean-Slate Communication Infrastructure: *The combination of communication media proposed by the process must minimise the discrepancies between requirements and media characteristics.* The prototypical implementation of the clean-slate plan-

ning provided traceable results using the CRC 666 CoMoNo model, the list of potential media, and the desired number of media. The analysis provided in Section 5.3.4 showed that a selection of only 5 media could provide a similar overall fit to the currently used media. It also shows that the media selection is subject to the law of diminishing marginal returns: Each additional medium provides less improvement than the previous.

R9 - Propose Add-On Communication Infrastructure: *The combination of communication media proposed by the process must include the currently deployed communication infrastructure and must minimise the discrepancies between requirements and media characteristics.* The prototypical implementation of the add-on planning showed expected results using the CRC 666 model, the list of current and potential media, and the desired number of additional media. Blogging, the suggested add-on medium with the biggest gain, would offer a solution for some of the manually reported issues like the lack of visibility of the other sub-projects current status. Video conferencing, the second best add-on suggestion, on the other hand would tackle some of the distance related issues by providing a way to spontaneously review physical objects without the need to travel.

R11 - Clear Visual Language: *More than 50% of users must consider the visual language easy to understand and the readability of the symbols must not be altered by a black and white print.* 89% of the interviewees agreed to the statement “The presentation of the diagram is easy to understand.” Of these, 67% fully agreed.

5.5 Conclusion

The prototypical implementation discussed in this chapter provided a complete overview over all tools and methods involved in the concept. The analysis of the communication characteristics proved their ability to differentiate all relevant media. The prototypical modelling tool together with the case study showed the general usability of the model and notation. 94% of the interviewees considered the diagram as helpful for the interview procedure and 89% considered the presentation of the diagram easy to understand.

Overall the analysis of the current state at the research centre did not reveal major communication issues. One aspect, which should be noted though, is the discrepancy between the importance of the document management system, highlighted in Figure 5.10, and the number of manually reported issues dealing with large files or the necessity of a central storage. Further steps to increase the awareness and acceptance of the document management system might be considered. The number of reported software or operating system incompatibilities was to be expected in an environment as heterogeneous as an interdisciplinary research centre.

Regarding potential add-on communication media, desktop video conferencing should be considered. Because blogging would require a considerable change in communication behaviour for many researchers at the CRC 666, the video conferencing option is more viable for the short term. With the installation of inexpensive webcams and the freely available video conferencing service of the German Research Network [Net13] many time consuming journeys could be avoided.

In the long run, collaborative writing solutions could provide ben-

efits, especially towards the end of the third phase of the CRC 666 when the final report becomes due. While professional solutions are only available as software as a service, alternative with reduced functionality like Etherpad [BHH11] could be investigated.

Chapter 6

Outlook

The presented concept puts the communication analyst in the position to define reasonable communication media capabilities. These decisions are simple to justify for most nominal characteristics like directionality, but especially the ratio scale characteristics participant multiplicity, editor multiplicity, and maximum distance are more ambiguous. Two additional approaches worth investigating would be the collective definition of communication media characteristics and the definition of the characteristics based on actual process data.

In order to implement the collective definition of media characteristics, a voting system would ideally be embedded into commonly used software. As companies implement Enterprise 2.0 strategies, a web dashboard could be a good starting point to include such system. The system would query the user from time to time about his judgement of the characteristics of a medium. Alternatively, the system could ask the user which of two offered media is better suited regarding a given characteristic in order to create a ranking using adapted pairwise comparison methods [Dav60]. By spreading the number of

necessary queries across time and a large number of users, the system could be implemented without too much user interference. Statistical analysis of the gathered data would also allow judging which characteristics have a general agreement between the users and which characteristics are more controversial.

For the second approach, the various communication media themselves would register and report their usage statistics. An email system could report how many recipients are included in each email; a wiki could report how many edits happen in a given time frame. A reservations system for meeting-rooms would report the travel distance of the participants, and so on. Again, statistical analysis could reveal reasonable limits for multiplicities, distances, and other characteristics.

The basic question regarding the first approach would be whether the sum of users has a better understanding of the realistic media characteristics compared to the communication analysts. Regarding the second approach it needs to be clarified how the as-is state relates to the real media characteristics. Often patterns of media use are established as a result of both media characteristics and user behaviour [DP94].

Although the prototypical implementation of the CoMoNo concept offers a graphical user interface for analysis and planning, a close integration with the graphical modelling environment would improve the usability. Using the analysis module, critical conversations could be highlighted directly while modelling. Based on the planning module, the communication analysts could visually compare the benefits of proposed improvement scenarios. Additionally, analysis and planning implementations with flexible weights could

provide live feedback regarding the impact of preferring one characteristic over the other.

Another potential application of the analysis and planning modules would be requirements definition for the development of new communication media. As was shown in Chapter 5, even when analysing all currently possible communication media, a residual level of issues may remain. Using these remaining issues to drive the development of new communication media could lead to new innovative communication solutions.

Chapter 7

Summary

Following an introduction to the general theme and an overview of the dissertation in the first chapter, the second chapter focussed on the current state in the areas of product development, communication theory, and business process planning. A review of the contemporary and upcoming product development methods product lifecycle management, simultaneous engineering, concurrent design, trust management, and agile approaches predicted an increase in communication intensity and complexity. Simply making more communication media available to the users would not be viable. According to critical mass theory, the resulting thinned-out number of users for each medium would prevent general acceptance. The examination of media selection theories identified measures like richness, synchronicity, immediacy of feedback, parallelism, or the used language, which characterise communication media. The investigation of current business process modelling approaches such as BPMN showed that many of the identified characteristics are not represented. The investigation also revealed that a stronger commu-

nication orientation in business process re-engineering results in a better outcome. These findings led to the conclusion that a fusion of findings from communication theory and business process modelling would be necessary.

The third and fourth chapter derived the requirements and proposed the CoMoNo concept. The overall goal of this concept is to provide a model and notation of communication processes which unites all of the above in order to support the analysis and planning of communication infrastructure. To achieve this, the BPMN conversation diagram is extended with the communication characteristics synchronicity, directionality, reception, visibility, reprocessability, content type, editor and participant multiplicity, and distance.

The prototypical implementation of a modelling environment and the analysis and planning procedures described in chapter five showed that the chosen communication characteristics can clearly distinguish the given communication media. Moreover, the application of the prototype in a case study at the CRC 666 proved the usability for analysis and planning. A majority of interviewees agreed that the notation was easy to understand and that the diagram was helpful during the interview.

The outlook in chapter six identified the collective definition of communication media characteristics as well as the process-derived definition as promising fields for future inquiry. In addition, the closer integration of the analysis and planning procedures with the modelling environment with flexible weights would be beneficial. Lastly, the analysis of residual issues, which remain with contemporary media, could lead to the development of valuable new communication media solutions.

Bibliography

[AE97] Chimay J. Anumba and Nosa F. O. Evbuomwan. “Concurrent engineering in design-build projects”. In: *Construction Management and Economics* 15.3 (1997), pp. 271–281. ISSN: 1466-433X. DOI: 10.1080/014461997373006 (cit. on p. 9).

[AG11] R. Anderl and H. Grabowski. “Virtuelle Produktentstehung”. In: K. H. Grote and J. Feldhusen. *Dubbel: Taschenbuch für den Maschinenbau*. Springer, 2011. ISBN: 9783642173059. DOI: 10.1007/978-3-642-17306-6 (cit. on p. 6).

[AH04] W. van der Aalst and K. van Hee. *Workflow Management: Models, Methods, and Systems*. Cooperative Information Systems. MIT Press, 2004. ISBN: 9780262720465 (cit. on pp. 48, 49, 117).

[And+07] R. Anderl et al. “Lifecycle Information Model for Higher Order Bifurcated Sheet Metal Products”. English. In: *The Future of Product Development*. Ed. by Frank-Lothar Krause. Springer Berlin Heidelberg, 2007, pp. 531–542.

ISBN: 978-3-540-69819-7. DOI: 10.1007/978-3-540-69820-3_52 (cit. on p. 59).

[And06] C. Anderson. *The Long Tail: Why the Future of Business is Selling Less of More*. Hyperion Books, 2006. ISBN: 9781401302375 (cit. on p. 35).

[And96] James Arthur Anderson. "Communication Theory Analysis". In: *Communication Theory: Epistemological Foundations*. Guilford Press, 1996, pp. 200–221. ISBN: 978-1572300835 (cit. on p. 17).

[ARV09] R. Anderl, J. Raßler, and D. Völz. "Modeling Global Product Development Projects - The Idea of the Product Collaboration Information Model". In: *16th European Concurrent Engineering Conference 2009, ECEC'2009 [and the] 6th Future Business Technology Conference, FUBUTEC'2009*. EUROSIS-ETI, Apr. 2009, pp. 99–104 (cit. on p. 6).

[Ass34] Associated Press. "German Postoffice To Use Television-telephone For Its Communication System". In: *The Evening Independent* 9-1 (Sept. 1934), p. 12 (cit. on p. 41).

[AVR08] R. Anderl, D. Völz, and T. Rollmann. "Knowledge Integration in Global Engineering". English. In: *Enterprise Interoperability III*. Ed. by Kai Mertins et al. Springer London, 2008, pp. 471–482. ISBN: 978-1-84800-220-3. DOI: 10.1007/978-1-84800-221-0_37 (cit. on p. 6).

[Bas07] Emek Basker. "The Causes and Consequences of Wal-Mart's Growth". In: *Journal of Economic Perspectives* 21 (3

2007), pp. 177–198. ISSN: 0895-3309. DOI: 10.1257/jep.21.3.177 (cit. on p. 94).

[Bec+01] Kent Beck et al. *Manifesto for Agile Software Development*. English. accessed 2012-01-15. 2001. URL: http://agilemanifesto.org/ (cit. on p. 15).

[BHH11] Cornelia Brodahl, Said Hadjerrouit, and Nils Kristian Hansen. "Collaborative Writing with Web 2.0 Technologies: Education Students' Perceptions." In: *Journal of Information Technology Education* 10 (2011), IIP73–IIP103. ISSN: 15393585 (cit. on p. 150).

[BHS06] Erik Brynjolfsson, Yu Jeffrey Hu, and Michael D. Smith. "From Niches to Riches: Anatomy of the Long Tail". In: *Sloan Management Review* 47 (2006), pp. 67–71. ISSN: 1532-9194 (cit. on p. 35).

[Cal+11] R. A. Calvo et al. "Collaborative Writing Support Tools on the Cloud". In: *Learning Technologies, IEEE Transactions on* 4.1 (Mar. 2011), pp. 88–97. ISSN: 1939-1382. DOI: 10.1109/TLT.2010.43 (cit. on p. 43).

[CK03] M. H. Christiansen and S. Kirby. "Language Evolution: The Hardest Problem in Science?" In: *Language Evolution*. Studies in the Evolution of Language. Oxford University Press, USA, 2003, pp. 1–15. ISBN: 9780199244836 (cit. on p. 39).

[CL11] Andre Charland and Brian Leroux. "Mobile application development: web vs. native". In: *Commun. ACM* 54.5 (May 2011), pp. 49–53. ISSN: 0001-0782. DOI: 10.1145/1941487.1941504 (cit. on p. 40).

[Cle92] K. J. Cleetus. “Definition of Concurrent Engineering”. In: *CERC Technical Report Series Research Note*. Vol. CERC-TR-RN-92-003. CERC Technical Report Series. Concurrent Engineering Research Center, West Virginia University, 1992 (cit. on p. 9).

[Coo+76] Martin Cooper et al. “Radio Telephone System”. English. 3,906,166. Feb. 10, 1976 (cit. on p. 40).

[Cra99] Robert T. Craig. “Communication Theory as a Field”. In: *Communication Theory* 9.2 (1999), pp. 119–161. ISSN: 1468-2885. DOI: 10.1111/j.1468-2885.1999.tb00355.x (cit. on pp. 17, 19).

[CW67] Harold Chestnut and Stanley Williams. “Business process modeling improves administrative control”. In: *Automation*. Penton Publishing Co., 1967, pp. 44–50. ISBN: 0-87769-041-3 (cit. on p. 45).

[Dav60] H. A. David. “The Method of Paired Comparisons”. In: vol. 60-2. Oct. 1960, pp. 1–16 (cit. on p. 151).

[Dee+12] Pete Deemer et al. *The SCRUM Primer 2.0*. Scrum Foundation, 2012 (cit. on pp. 15, 16).

[Den+98] Alan R. Dennis et al. “Beyond media richness: An empirical test of media synchronicity theory.” In: *Proceedings of the 31st Hawaii International Conference on System Sciences*. 1998, pp. 48–57 (cit. on pp. 30, 116).

[DFV08] Alan R. Dennis, Robert M. Fuller, and Joseph S. Valacich. “Media, Tasks, and Communication Processes: A Theory of Media Synchronicity”. In: *MIS Quarterly* 32.3 (2008), pp. 575–600. ISSN: 0276-7783 (cit. on pp. 31, 90, 116).

[DK98] A. R. Dennis and S. T. Kinney. “Testing media richness theory in the new media: The effects of cues, feedback, and task equivocality”. In: *Information Systems Research* 9.3 (1998), pp. 256–274. ISSN: 1526-5536. DOI: 10.1287/isre.9.3.256 (cit. on p. 30).

[DL84] Richard L. Daft and Robert H. Lengel. “Information richness: a new approach to managerial behavior and organization design.” In: *Office of Naval Research Technical Report Series*. Office of Naval Research, 1984, pp. 191–233 (cit. on pp. 28–30, 90, 116).

[DL86] Richard L. Daft and Robert H. Lengel. “Organizational Information Requirements, Media Richness and Structural Design.” In: *Management Science* 32.5 (May 1986), pp. 554–571. ISSN: 0025-1909. DOI: 10.1287/mnsc.32.5.554 (cit. on pp. 28, 116).

[DLT87] Richard L. Daft, Robert H. Lengel, and Linda Kiebe Trevino. “Message Equivocality, Media Selection, and Manager Performance: Implications for Information Systems.” In: *MIS Quarterly* 11.3 (1987), pp. 354–366. ISSN: 0276-7783 (cit. on pp. 28, 90, 116).

[Dou+00] Paul Dourish et al. “Extending document management systems with user-specific active properties”. In: *ACM Trans. Inf. Syst.* 18.2 (Apr. 2000), pp. 140–170. ISSN: 1046-8188. DOI: 10.1145/348751.348758 (cit. on p. 45).

[DP94] Gerardine DeSanctis and Marshall Scott Poole. “Capturing the Complexity in Advanced Technology Use: Adaptive Structuration Theory.” In: *Organization Science* 5.2

(1994), pp. 121–147. ISSN: 1047-7039. DOI: 10.1287/orsc.5.2.121 (cit. on p. 152).

[DV99] Alan R. Dennis and J. S. Valacich. "Rethinking media richness: towards a theory of media synchronicity". In: *System Sciences, 1999. HICSS-32. Proceedings of the 32nd Annual Hawaii International Conference on.* 1999, 10 pp. DOI: 10.1109/HICSS.1999.772701 (cit. on pp. 30, 90, 116).

[Ear11] Alan Earls. *The rise and rise of BPMN for process modeling.* English. accessed 2012-10-11. ebizQ. June 2011. URL: http://www.ebizq.net/topics/bpm_process_modeling/features/13227.html (cit. on p. 53).

[EG05] Anja Ebersbach and Markus Glaser. "Wiki". German. In: *Informatik-Spektrum* 28 (2 2005), pp. 131–135. ISSN: 0170-6012. DOI: 10.1007/s00287-005-0480-7 (cit. on pp. 37, 43).

[Eur05] European Commission. *The new SME definition - User guide and model declaration.* accessed 2013-01-23. Jan. 2005. URL: http://ec.europa.eu/enterprise/policies/sme/files/sme_definition/sme_user_guide_en.pdf (cit. on p. 94).

[Eve+97] W. Eversheim et al. "Simultaneous engineering approach to an integrated design and process planning". In: *European Journal of Operational Research* 100.2 (1997), pp. 327–337. ISSN: 0377-2217. DOI: 10.1016/S0377-2217(96)00293-7 (cit. on p. 10).

[Fei12] Ewgenij Feicha. “Analyse der Informationsflüsse des SFBs 666 und Konzeptionierung einer benutzerorientierten Abbildungsmethodik”. Studienarbeit. Fachgebiet Datenverarbeitung in der Konstruktion - Technische Universität Darmstadt, 2012 (cit. on pp. 60, 61).

[Fis01] Steven Roger Fischer. *A History of Writing*. Globalities Series. Reaktion Books, 2001. ISBN: 9781861891679 (cit. on pp. 39, 41).

[Gan10] Henry Laurence Gantt. *Work, wages, and profits : their influence on the cost of living*. Works Management Library. The Engineering Magazine, 1910. ISBN: 978-1171595229 (cit. on p. 45).

[GG21] Frank Bunker Gilbreth and Lillian Moller Gilbreth. “Process Charts - First Steps in Finding the One Best Way to Do Work”. In: *Annual Meeting of The American Society of Mechanical Engineers*. American Society of Mechanical Engineers. Dec. 1921 (cit. on p. 45).

[GH06] Scott A. Golder and Bernardo A. Huberman. “Usage patterns of collaborative tagging systems”. In: *Journal of Information Science* 32.2 (2006), pp. 198–208. ISSN: 1741-6485. DOI: 10.1177/0165551506062337 (cit. on p. 35).

[Gia01] George M. Giaglis. “A Taxonomy of Business Process Modeling and Information Systems Modeling Techniques”. In: *International Journal of Flexible Manufacturing Systems* 13 (2 2001), pp. 209–228. ISSN: 0920-6299. DOI: 10.1023/A:1011139719773 (cit. on pp. 46, 48, 117).

[GL91] Walter A. Green and Harold Lazarus. “Are Today’s Executives Meeting with Success?” In: *Journal of Management Development* 10-1 (1991), pp. 14–25. ISSN: 0262-1711. DOI: 10.1108/02621719110139034 (cit. on pp. 39, 186).

[Gro+09] Peter Groche et al. “Herstellung multifunktionaler Blechprofile”. In: *Werkstatttechnik online* 99.10 (2009), pp. 712–720 (cit. on p. 58).

[GS10] Peter Groche and Wolfram Schmitt. “Integrale Blechbauweise höherer Verzweigungsordnung: Von der Entwicklung zur Anwendung”. In: *Tagungsband 3. Zwischenkolloquim SFB666*. Technische Universität Darmstadt. Meisenbach Verlag GmbH, Bamberg, 2010, pp. 3–12 (cit. on p. 58).

[Har28] R. V. L. Hartley. “Transmission of Information”. In: *Bell System Technical Journal* 7-3 (July 1928), pp. 535–563. ISSN: 0005-8580 (cit. on p. 24).

[Her+04] S. C. Herring et al. “Bridging the gap: a genre analysis of Weblogs”. In: *System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on*. Jan. 2004, 11 pp. ISBN: 0-7695-2056-1. DOI: 10.1109/HICSS.2004.1265271 (cit. on p. 43).

[Hil+10] F. Hillebrand et al. *Short Message Service (SMS): The Creation of Personal Global Text Messaging*. Wiley, 2010. ISBN: 9780470689936 (cit. on p. 41).

[Hir+12] M. Hirth et al. “Wikipedia and its network of authors from a social network perspective”. In: *Communications and*

Electronics (ICCE), 2012 Fourth International Conference on. Aug. 2012, pp. 119–124. DOI: 10.1109/CCE.2012.6315882 (cit. on p. 43).

[IEE08] IEEE Computer Society. *IEEE Standard for Information Technology- Portable Operating System Interface (POSIX) Base Specifications, Issue 7*. Tech. rep. Jan. 2008, pp. c1–3826. DOI: 10.1109/IEEESTD.2008.4694976 (cit. on p. 92).

[IEE11] IEEE. *IEEE Guide–Adoption of the Project Management Institute (PMI(R)) Standard A Guide to the Project Management Body of Knowledge (PMBOK(R) Guide)–Fourth Edition*. Tech. rep. 2011, pp. 1–508. DOI: 10.1109/IEEESTD.2011.6086685 (cit. on p. 112).

[IEE91] IEEE Computer Society. *IEEE Standard Computer Dictionary. A Compilation of IEEE Standard Computer Glossaries*. Tech. rep. IEEE610. 1991, p. 1. DOI: 10.1109/IEEESTD.1991.106963 (cit. on p. 111).

[Int03] Internet Engineering Task Force. *Internet Message Access Protocol - Version 4rev1*. English. Tech. rep. RFC5321. University of Washington, Mar. 2003 (cit. on p. 42).

[Int08a] Internet Engineering Task Force. *Internet Message Format*. English. Tech. rep. RFC5322. Aug. 2008 (cit. on p. 42).

[Int08b] Internet Engineering Task Force. *Simple Mail Transfer Protocol*. English. Tech. rep. RFC5321. Aug. 2008 (cit. on p. 42).

[Int96] Internet Engineering Task Force. *Post Office Protocol - Version 3*. English. Tech. rep. RFC1939. Carnegie Mellon, May 1996 (cit. on p. 42).

[Jäs+07] Robert Jäschke et al. "Tag Recommendations in Folksonomies". In: *Knowledge Discovery in Databases*. Ed. by Joost N. Kok et al. Vol. 4702. Lecture Notes in Computer Science. Springer, 2007, pp. 506–514. ISBN: 978-3-540-74975-2. DOI: 10.1007/978-3-540-74976-9_52 (cit. on p. 35).

[Kar09] Dennis Karwatka. "Alexander Bain and the Fax Machine." In: *Tech Directions* 69.4 (2009), p. 11. ISSN: 1062-9351 (cit. on p. 41).

[KB09] Benjamin Kellermann and Rainer Böhme. "Privacy-Enhanced Event Scheduling". In: *Computational Science and Engineering, 2009. CSE '09. International Conference on*. Vol. 3. Aug. 2009, pp. 52–59. DOI: 10.1109/CSE.2009.270 (cit. on p. 44).

[KDK08] Ned Kock, Azim Danesh, and Paul Komiak. "A discussion and test of a communication flow optimization approach for business process redesign." In: *Knowledge and Process Management* 15.1 (2008), pp. 72–85. ISSN: 1092-4604. DOI: 10.1002/kpm.301 (cit. on p. 55).

[KLL09] Ryan K. L. Ko, Stephen S. G. Lee, and Eng Wah Lee. "Business process management (BPM) standards: a survey". In: *Business Process Management Journal* 15.5 (2009), pp. 744–791. ISSN: 1463-7154. DOI: 10.1108/14637150910987937 (cit. on pp. 47, 49, 118).

[KM96] Ned Kock and Robert J. McQueen. “Product flow, breadth and complexity of business processes: An empirical study of 15 business processes in three organizations”. In: *Business Process Re-engineering & Management Journal* 2.2 (1996), pp. 8–22. ISSN: 1355-2503. DOI: 10.1108/14637159610148040 (cit. on p. 55).

[Koc+09] Ned Kock et al. “Communication flow orientation in business process modeling and its effect on redesign success: Results from a field study.” In: *Decision Support Systems* 46.2 (2009), pp. 562–575. ISSN: 0167-9236. DOI: 10.1016/j.dss.2008.10.002 (cit. on pp. 55–57).

[Koc03] Ned Kock. “Communication-focused business process redesign: assessing a communication flow optimization model through an action research study at a defense contractor”. In: *Professional Communication, IEEE Transactions on* 46.1 (Mar. 2003), pp. 35–54. ISSN: 0361-1434. DOI: 10.1109/TPC.2002.808350 (cit. on p. 55).

[Lik32] Rensis Likert. “A technique for the measurement of attitudes.” In: *Archives of Psychology* 22.140 (1932). ISSN: 0272-6653 (cit. on p. 134).

[LMB09] U. Lindemann, M. Maurer, and T. Braun. *Structural Complexity Management*. Springer, 2009. ISBN: 9783540878896. DOI: 10.1007/978-3-540-87889-6 (cit. on p. 8).

[Mar87] M. Lynne Markus. “Toward a “Critical Mass” Theory of Interactive Media”. In: *Communication Research* 14.5 (Oct.

1987), pp. 491–511. ISSN: 0093-6502. DOI: 10.1177/009365087014005003 (cit. on p. 22).

[May09] Horst Otto Mayer. *Interview und schriftliche Befragung*. Ed. by -. 5. Oldenbourg, 2009. ISBN: 978-3-486-59070-8 (cit. on p. 132).

[McA06] Andrew McAfee. "Enterprise 2.0: The Dawn of Emergent Collaboration." In: *MIT Sloan Management Review* 47.3 (2006), pp. 21–28. ISSN: 1532-9194 (cit. on pp. 34, 37, 117).

[McA09] Andrew McAfee. *Enterprise 2.0: new collaborative tools for your organization's toughest challenges*. Boston, MA: Harvard Business School Press, 2009. ISBN: 978-1422125878 (cit. on p. 38).

[McC96] Jenny C. McCune. "The intranet: Beyond e-mail". In: *Management Review* 85.11 (1996), p. 23. ISSN: 0025-1895 (cit. on p. 44).

[Mor38] C. W. Morris. *Foundations of the theory of signs*. International Encyclopedia of Unified Science. University of Chicago Press, 1938. ISBN: 978-0226575773 (cit. on p. 25).

[Mue12] Jennifer S. Mueller. "Why individuals in larger teams perform worse". In: *Organizational Behavior and Human Decision Processes* 117.1 (2012), pp. 111–124. ISSN: 0749-5978. DOI: 10.1016/j.obhdp.2011.08.004 (cit. on p. 94).

[Nat93] National Institute of Standards and Technology. *Integration Definition for Function Modeling (IDEF0)*. Tech. rep. Dec. 1993. URL: http://www.idef.com/pdf/idef0.pdf (cit. on p. 45).

[Net13] German Research Network. *DFNVC - The Video Conference Service of the German Research Network*. DFN. 2013. URL: https://www.vc.dfn.de/en.html (cit. on p. 149).

[Obj05a] Object Management Group. *UML 2.0 Infrastructure Specification*. Tech. rep. July 2005. URL: http://www.omg.org/spec/UML/2.0/Infrastructure/PDF/ (cit. on p. 48).

[Obj05b] Object Management Group. *UML 2.0 Superstructure Specification*. Tech. rep. July 2005. URL: http://www.omg.org/spec/UML/2.0/Superstructure/PDF/ (cit. on p. 48).

[Obj10] Object Management Group. *BPMN 2.0 by Example*. English. Tech. rep. June 2010. URL: http://www.omg.org/spec/BPMN/2.0/examples/PDF (cit. on p. 48).

[Obj11] Object Management Group. *Business Process Model and Notation (BPMN)*. English. Tech. rep. Jan. 2011. URL: http://www.omg.org/spec/BPMN/2.0 (cit. on pp. 48, 53, 54).

[OBL09] Kenton O'Hara, Alison Black, and Matthew Lipson. "Media Spaces and Mobile Video Telephony". In: *Media Space 20+ Years of Mediated Life*. Ed. by Steve Harrison. Computer Supported Cooperative Work. Springer London, 2009, pp. 303–323. ISBN: 978-1-84882-482-9. DOI: 10.1007/978-1-84882-483-6_19 (cit. on p. 41).

[ORe05] Tim O'Reilly. *What Is Web 2.0 - Design Patterns and Business Models for the Next Generation of Software*. English. accessed 2012-09-13. O'Reilly Media, Inc. Sept. 2005. URL:

http://oreilly.com/web2/archive/what-is-web-20.html (cit. on p. 34).

[PD99] B.J. Pine and S. Davis. *Mass Customization: The New Frontier in Business Competition*. Harvard Business School Press, 1999. ISBN: 9780875849461 (cit. on p. 8).

[PWB07] Gerhard Pahl, K. Wallace, and L. Blessing. *Engineering Design: A Systematic Approach*. Springer, 2007. ISBN: 9781846283192. DOI: 10.1007/978-1-84628-319-2 (cit. on pp. 7, 8, 10, 11).

[PZL08] Cesare Pautasso, Olaf Zimmermann, and Frank Leymann. "Restful web services vs. big web services: making the right architectural decision". In: *Proceedings of the 17th international conference on World Wide Web*. WWW '08. Beijing, China: ACM, 2008, pp. 805–814. ISBN: 978-1-60558-085-2. DOI: 10.1145/1367497.1367606 (cit. on p. 36).

[Rap11] Rapid-I GmbH. *RapidMiner 5.0 Manual*. http://rapid-i.com/. accessed 2011-09-01. Sept. 2011. URL: http://rapid-i.com/ (cit. on p. 120).

[Rez61] F. Reza. *An Introduction to information theory*. Dover Books on Mathematics Series. Dover Publications, Incorporated, 1961. ISBN: 9780486682105 (cit. on p. 25).

[RG08] Jens Ringler and Peter Groche. "Spaltbiegen - Ein neues Verfahren für integrale Verzweigungen aus der Blechmitte". In: *Tagungsband 2. Zwischenkolloquium SFB 666* (2008), pp. 63–71 (cit. on p. 58).

[RN01] N. C. Jr Romano and J. F. Jr Nunamaker. “Meeting analysis - findings from research and practice”. In: *System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on*. Jan. 2001, 13 pp. DOI: 10.1109/HICSS.2001.926253 (cit. on pp. 39, 186).

[Rob06] D. Robertson. “The great telephone mystery.” In: *IEE Review* 52.2 (2006), pp. 44–48. ISSN: 0953-5683. DOI: 10.1049/ir:20060204 (cit. on p. 40).

[Rol+11] T. H. Rollmann et al. “Feature precedence graphs as an approach for the forming operations planning of integral sheet metal parts”. In: *Assembly and Manufacturing (ISAM), 2011 IEEE International Symposium on*. May 2011, pp. 1–6. DOI: 10.1109/ISAM.2011.5942355 (cit. on p. 59).

[Rom04] H. C. Romesburg. *Cluster Analysis For Researchers*. Lulu Press, 2004. ISBN: 9781411606173 (cit. on pp. 99, 120).

[RR12] Suzanne Robertson and James Robertson. *Mastering the Requirements Process: Getting Requirements Right*. Pearson Education, 2012. ISBN: 9780132942843 (cit. on pp. 65, 66).

[Sch99a] A. W. Scheer. *ARIS - Business Process Frameworks*. Springer, 1999. ISBN: 978-3-642-58529-6. DOI: 10.1007/978-3-642-58529-6 (cit. on p. 50).

[Sch99b] A. W. Scheer. *ARIS - Business Process Modeling*. Third Edition. Springer, 1999. ISBN: 978-3-642-97998-9. DOI: 10.1007/978-3-642-97998-9 (cit. on p. 50).

[Sha36] Claude Elwood Shannon. “A Symbolic Analysis of Relay and Switching Circuits”. Masters Thesis. Massachusetts Institute of Technology, 1936 (cit. on p. 27).

[Sha48a] Claude Elwood Shannon. “A Mathematical Theory of Communication”. In: *Bell System Technical Journal* 27.3 (1948), pp. 379–423. ISSN: 0005-8580 (cit. on pp. 25, 26, 116).

[Sha48b] Claude Elwood Shannon. “A Mathematical Theory of Communication”. In: *Bell System Technical Journal* 27.4 (1948), pp. 623–656. ISSN: 0005-8580 (cit. on p. 26).

[Sma+95] Asim Smailagic et al. “Benchmarking an interdisciplinary concurrent design methodology for electronic/mechanical systems”. In: *Proceedings of the 32nd annual ACM/IEEE Design Automation Conference*. DAC ’95. San Francisco, California, USA: ACM, 1995, pp. 514–519. ISBN: 0-89791-725-1. DOI: 10.1145/217474.217580 (cit. on p. 12).

[Smi12] Aaron Smith. *46 Percent of American adults are smartphone owners*. English. accessed 2012-11-01. Pew Research Center. Mar. 2012. URL: http://pewinternet.org/~/media/Files/Reports/2012/Smartphone%20ownership%202012.pdf (cit. on p. 40).

[Sof12a] Software AG. *Fact Sheet ARIS Business Architect & Designer*. accessed 2013-01-04. Apr. 2012. URL: http://www.softwareag.com/ (cit. on p. 124).

[Sof12b] Software AG. *Server Installation and Administration Guide*. Version 7.2 - Service Release 3. Software AG. Darmstadt, Germany, Mar. 2012 (cit. on p. 127).

[STA05] A. W. Scheer, Oliver Thomas, and Otmar Adam. "Process Modeling Using Event-Driven Process Chains". In: *Process-Aware Information Systems: Bridging People and Software Through Process Technology*. Ed. by M. Dumas, W. M. van der Aalst, and A. H. Hofstede. John Wiley & Sons, 2005, pp. 119–145. ISBN: 978-0471663065 (cit. on pp. 48, 50–52).

[Ste06] Greg L. Stewart. "A Meta-Analytic Review of Relationships Between Team Design Features and Team Performance". In: *Journal of Management* 32.1 (2006), pp. 29–55. ISSN: 1557-1211. DOI: 10.1177/0149206305277792 (cit. on p. 94).

[Ste46] Stanley Smith Stevens. "On the theory of scales of measuremen". In: *Science* 103 (June 1946), pp. 677–680. ISSN: 1095-9203 (cit. on p. 96).

[Sut+07] Jeff Sutherland et al. "Distributed Scrum: Agile Project Management with Outsourced Development Teams". In: *System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference on*. Jan. 2007, 274a. DOI: 10.1109/HICSS.2007.180 (cit. on p. 17).

[SW64] Claude E. Shannon and Warren Weaver. *The Mathematical Theory of Communication*. Tenth Printing. The University of Illinois Press, Urbana, 1964. ISBN: 978-0252725487 (cit. on p. 28).

[SWA11] A. Schüle, O. Weitzmann, and R. Anderl. “Feature-based Modeling of Bifurcated Sheet Metal Products”. In: *Proceedings of the 12th Asia Pacific Industrial Engineering and Management Systems Conference (APIEMS 2011), Beijing, China* (Oct. 2011) (cit. on p. 59).

[TF91] Sarosh N. Talukdar and Steven J. Fenves. “Towards a framework for concurrent design”. In: *Computer-Aided Cooperative Product Development*. Ed. by Duvvuru Sriram, Robert Logcher, and Shuichi Fukuda. Vol. 492. Lecture Notes in Computer Science. Springer, 1991, pp. 140–151. ISBN: 978-3-540-54008-3. DOI: 10.1007/BFb0014277 (cit. on p. 10).

[Tom12] Raymond Tomlinson. *The First Network Email*. English. accessed 2012-12-07. 2012. URL: http://openmap.bbn.com/~tomlinso/ray/firstemailmain.html (cit. on p. 42).

[Uni09] United Nations. *World Population Prospects - The 2008 Revision*. Ed. by Department of Economic and Social Affairs - Population Division. United Nations, 2009 (cit. on p. 94).

[VAK13] D. Völz, R. Anderl, and M. Krastel. “Die Rolle von Vertrauen im Wissensschutz - Ergebnisbericht zur softwaregestützten TRUST-Entscheidungsunterstützungsapplikation”. In: *PLM Portal* (2013). URL: http://www.plmportal.org/forschung-details/items/die-rolle-von-vertrauen-im-wissensschutz-ergebnisbericht-

zur - softwaregestuetzten - trust - entscheidungsunterstuetzungsapplikation . html (cit. on pp. 14, 42).

[VDA12] VDA. *VDA-Empfehlung zur Abstimmung der Datenlogistik in SE-Projekten*. Tech. rep. 4961/3. Verband der Automobilindustrie e.V., Apr. 2012 (cit. on pp. 12, 13).

[VDI93] VDI. *Systematic approach to the development and design of technical systems and products*. Tech. rep. VDI 2221. Verein Deutscher Ingenieure, May 1993. URL: http://www.vdi.de/2221 (cit. on p. 8).

[Wal12] Walmart. *Walmart 2012 Annual Report*. Wal-Mart Stores, Inc., 2012 (cit. on p. 94).

[Wei+12] O. Weitzmann et al. "An object-oriented information model for the representation of free form sheet metal parts in integral style". In: *Tools and Methods of Competitive Engineering* (2012). Karlsruhe, Germany (cit. on p. 59).

[WG12] Dave West and Tom Grant. "Agile Development: Mainstream Adoption Has Changed Agility". In: *Application Development & Program Management Professional* (Jan. 2012) (cit. on pp. 14, 15).

[Wik12] Wikipedia. *WikiWikiWeb*. English. oldid: 507848407. Wikimedia Foundation. Sept. 2012. URL: https://en.wikipedia.org/w/index.php?title=WikiWikiWeb&oldid=507848407 (cit. on p. 43).

[Win+88] Robert I. Winner et al. “The Role of Concurrent Engineering in Waeapons System Acquisition”. In: *Institute for Defense Analyses Report*. Insitute for Defense Analyses Report R-338 (Dec. 1988). ISSN: 0073-8662 (cit. on p. 9).

[Yan+10] Gangjun Yang et al. “Agile industrial design management based on Scrum”. In: *Computer-Aided Industrial Design Conceptual Design (CAIDCD), 2010 IEEE 11th International Conference on*. Vol. 2. Nov. 2010, pp. 889–891. DOI: 10.1109/CAIDCD.2010.5681880 (cit. on p. 15).

[Yao12] Yaoqiang, Inc. *Yaoqiang BPMN Editor*. accessed 2013-01-04. Dec. 2012. URL: http://bpmn.sourceforge.net/ (cit. on p. 124).

[Yu+08] Jin Yu et al. “Understanding Mashup Development”. In: *Internet Computing, IEEE* 12.5 (Oct. 2008), pp. 44–52. ISSN: 1089-7801. DOI: 10.1109/MIC.2008.114 (cit. on p. 35).

[ZB98] Ilze Zigurs and Bonnie K. Buckland. “A Theory of Task/Technology Fit and Group Support Systems Effectiveness.” In: *MIS Quarterly* 22.3 (1998), pp. 313–334. ISSN: 0276-7783. DOI: 10.1145/344241.344244 (cit. on pp. 32, 116).

[ZK08] Ilze Zigurs and Deepak Khazanchi. “From Profiles to Patterns: A New View of Task-Technology Fit.” In: *Information Systems Management* 25.1 (2008), pp. 8–13. ISSN: 1058-0530. DOI: 10.1080/10580530701777107 (cit. on pp. 32, 116).

Appendix A

Templates

Medium	**Dir.**	**Sync.**	**Vis.**	**Repr.**	**Rec.**	**Dist.**	**E. Mult.**	**P. Mult.**	**Cont.**

u: uni-directional, b: bi-directional; s: synchronous, a: asynchronous; O:OTR, P:private, G:group, W:world; r:reprocessable, t:transient; e:explicit, i: implicit;
Au: audio, Da: date, De: decision, Fi: file, Gr: graphic, Ph: physical, SD: struct. data, Ta: table, Te: text, Vi: video

Table A.1: Template: Communication media characteristics

Conversation	Dir.	Sync.	Vis.	Repr.	Rec.	Dist.	E. Mult.	P. Mult.	Cont.
u: uni-directional, b: bi-directional; s: synchronous, a: asynchronous; O:OTR, P:private, G:group, W:world; r:reprocessable, t:transient; e:explicit, i: implicit; Au: audio, Da: date, De: decision, Fi: file, Gr: graphic, Ph: physical, SD: struct. data, Ta: table, Te: text, Vi: video									

Table A.2: Template: Conversation characteristics

A.1 CoMoNo Interview Guideline

Interviewee Data

- Name:
- Sub-Project:
- Room/Building:
- Tenure:
- Position:

Partners

- With whom do you exchange project related information?
- How many senders and receivers are involved in this conversation?

Communication Content

- What type of content is exchanged in this conversation?

Communication Requirements

- Do you require a reply?
- Do you require the reply immediately? Are all participants in this conversation available at the same time?
- Do you require an explicit confirmation that the recipient received the message?
- Should the visibility of the message be limited?
- Should each participant be able to reprocess the content of this conversation later on?
- How many should be able to edit synchronously?

Available Media

- Which media are available?

Communication Issues

- What communication issues have you come across recently or in the past?

A.2 Notation Introduction

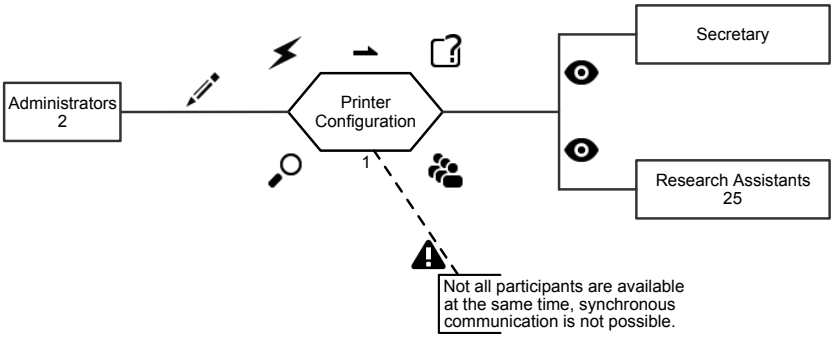

Figure A.1: CoMoNo diagram introduction

Participants

- Participant multiplicity
- Editor multiplicity
- Location
- Position
- Sender, receiver, or both

Conversation

- Synchronous or asynchronous
- Uni-directional or bi-directional
- Explicit reception or implicit reception
- Reprocessable or transient
- Off-the-record, private, group, or public visibility

Content Types

Au: audio, Da: date, De: decision, Fi: file, Gr: graphic, Ph: physical, SD: structured data, Ta: table, Te: text, Vi: video

Communication Issues with a brief description.

Appendix B

Communication Media Characteristics

The following sections explain the characteristics of the individual communication media introduced in Section 2.2.8. Each entry provides a brief summary of its characteristics following the notation defined in Section 4.1.2 and the potential distance (d), simultaneous editor multiplicity (e), participant multiplicity (p), and possible content types (audio (au), date (da), decision (de), file (fi), graphic (gr), physical (ph), struct. data (sd), table (ta), text (te), video (vi)).

Face-to-Face

(⇌,⚡,⃠/ ,,☑,d:1000,e:1,p:2,(au,gr,ph,ta,te,vi))

In a face-to-face conversation, it is hardly possible for the two participants not to communicate as even not saying anything carries information, thus the conversation is always bi-directional. As both participants have to be present at the same time and because they receive immediate feedback, a face-to-face conversation is considered

synchronous and explicit. An important characteristic of face-to-face communication in additional to the normal privacy is the ability to discuss topics *off-the-record* as neither participant can prove what the other one stated. As a conversation is commonly not recorded, it is not possible to review or search its contents later on. Not having to use any additional devices is an advantage but it also limits the distance for spontaneous face-to-face communication. If all participants are situated in the same complex, the distance is considered reasonable.

Group Meeting

(⇌,⚡,📍/🐾,🔍,☑,d:1000,e:10,p:50,(au,gr,ph,ta,te,vi))

A group meeting is similar to a private face-to-face communication. It differs in that it does not offer the *off-the-record* capability because of the number of potential witnesses. It also requires some minimal infrastructure like a room and often a white-board. In order to make considerations and decisions binding, meeting minutes are usually recorded. The number of participants is limited by the size of the room and the approach used to structure the process of the conversation. The literature review on meeting analysis research by Romano and Nunamaker provides a good overview of recommended meeting sizes for different contexts [RN01]. They suggest an ideal size for decision-making or problem-solving meetings of seven to fifteen participants. According to another study by Green and Lazarus, 70 per cent of over 1000 responses from executives stated that the typical meeting size was 15 participants or less [GL91]. Using the levels defined for multiplicities, this is mapped to the next larger step, a small enterprise.

Presentation

(➡,⚡,📍,🔊,☑,d:1000,e:10,p:250,(au,gr,ph,ta,te,vi))

Based on a meeting, the presentation changes the structure of the conversation to a uni-directional one. This also changes the numbers of possible senders and receivers. While a presentation is usually held by a single individual or a small group, it can reach a large audience of a few hundred participants. It does require an adequate room, which should be equipped with a microphone system if larger groups should be addressed.

Telephone

(⇌,⚡,🚫/📍,🔊,☑,d:100000000,e:1,p:2,(au))

A conversation via telephone is essentially the same as a face-to-face conversation limited to the exchange of audio signals. Based on the legal limitations to wire-tapping and recording of phone calls, even the *off-the-record* capability can be assumed for most cases.

Telephone Conference

(⇌,⚡,📍,🔊,☑,d:100000000,e:10,p:250,(au))

For most of its characteristics, a telephone conference resembles a group meeting mediated through a telephone. Because the telephone conference is not bounded by physical aspects like room size, a larger number of passive participants can be integrated. The use of telephones limits the content to audio signals.

Video Conference

(⇌,⚡,📍,🔊,☑,d:100000000,e:10,p:250,(au,gr,ta,te,vi))

Compared to a telephone conference, the video conference also allows video signals to be transmitted.

Short Message Service

(➞/⇌,⏱,📍,🔑,📝/☑,d:100000000,e:1,p:10,(te))

A short message sent from mobile phone to mobile phone only allows very brief plain text content. Depending on the configuration it can be used uni-directionally (hidden sender) or bi-directionally. If the receiving mobile phone is switched off when a message is sent, the message is stored in the system and delivered later on when the phone becomes available again. Short messages are only visible to the specific recipient who can reprocess the full content of all received message using his mobile phone. Another feature of short message is the explicit notification when a message was received by the counterpart.

Mail

(➞/⇌,⏱,📍,🔑,📝/☑,d:100000000,e:1,p:50,(gr,ta,te))

Depending on the sender's decision to include a valid reply address, a normal mail can be used uni-directionally as well as bi-directionally and the transport occurs asynchronously. In any case, the content of the mail is only privately visible to the indicated recipient. As a letter can be archived, it can be available for later reprocessing. If the sender chose to use registered mail explicit reception is guaranteed, otherwise mail only offers implicit reception.

Fax

(➞/⇌,⏱,📠,🔑,☑,d:100000000,e:1,p:50,(gr,ta,te))

Similar to the standard mail described above, the sender of a fax can decide to hide the reply fax number. This allows the fax system to be used in a uni-directional way. As a fax machine is usually turned on 24/7, the recipient does not need to be available when a fax is transmitted. Because many fax machines are placed in a location acces-

sible to co-workers, privacy should not be taken as granted. The received faxes can be archived and are thus available for later reprocessing. As the fax machines record errors during the transmission process, the reception is considered explicit. While only one participant can send a fax at one time, many fax machines support the delivery of the same message to many recipients sequentially.

Email

(⇌,⏱,📍,🔍,📝/☑,d:100000000,e:1,p:50,(fi,gr,ta,te))

Because most email systems enforce the use of a reply-to address, it is usually possible to reply to the sender of an email. Messages are stored by the recipients email system until delivery and are only visible to the intended recipient. Current email clients implement advanced search possibilities in order to sift through the content of previously received messages. They also implement features to acknowledge the reception of a message asking for explicit confirmation. Having to add the recipients manually to the email, limits the reasonable amount of participants, which can be addressed without using a newsletter or mailinglist system.

Email Newsletter

(➡,⏱,📍/👥,🔍,📝,d:100000000,e:1,p:1500000 ,(fi,gr,ta,te))

As with mail and fax, it is possible to enforce uni-directional email communication by providing an inactive address as reply-to (“noreply@...”). Because of the commonly large number of recipients, newsletters do not require explicit confirmation of the reception.

Email Mailinglist

(⇌,⏱,📍/👥,🔍,📝,d:100000000,e:1,p:250,(fi,gr,ta,te))

Contrary to the pure informational character of newsletters, mailinglists focus on bi-directional conversation between all participants.

Many mailinglist systems also provide a web-archive of all conversations on the list. Again, because of the large number of participants the use of explicit conformations is not useful. All other characteristics are derived from email communication.

Publication

(→,⏱,🌐,🔍,?,d:100000000,e:5,p:1000000000,(gr,ta,te))

A scientific publication provides the edited knowledge of the authors to the general public. Although feedback is generally possible through other media, the publication itself is provided in a unidirectional and implicit fashion on a asynchronous platform. Using common standards, many publication platforms exchange meta-data in order to improve searchability.

Blog

(→ / ⇌,⏱,👥/🌐,🔍,?,d:100000000,e:1,p:10000000,(au,fi,gr,ta,te,vi))

Depending on the individual configuration, a blog can provide information in a uni-directional fashion from one to many or allow the recipients to reply to a blog post via comments. Either way, the communication is asynchronous and does not provide explicit confirmation. Though most blogs are targeted at the general public, it is possible to limit the circle of potential recipients. In order to make it easy for the recipient to find the desired information, blogs are commonly full-text searchable and thus reprocessable.

Wiki

(⇌,⏱,👥/🌐,🔍,?,d:100000000,e:50,p:10000000,(fi,gr,ta,te))

A wiki allows multiple authors the synchronous and bi-directional editing of a common text, which can be enriched by tables, graphics, or even videos. For most implementations, the number of synchronous editors per article is limited by the number of individual

sections. Some wikis, so called “walled gardens”, are targeted at a limited group of recipients, while others are open to the general public. Wikis are generally reprocessable but do not offer explicit notifications about the reception.

Collaborative Writing

(⇌,↯/⏱, 📍/🐾,🔧,📝/☑,d:100000000,e:50,p:250,(gr,ta,te))

The collaborative writing of documents resembles the editing of wikis, but adds synchronous editing, more fine-grained privacy control, and explicit reception notifications.

Decision Support System

(⇌,⏱,🚫/ 📍/🐾,🔧,📝,d:100000000,e:250,p:250,(da,de,te))

After the sender proposes a poll, the receivers communicate their decision back to the originator asynchronously. Depending on the implementation of the decision support system, even anonymous off-the-record polling can be possible. Though it is clearly visible who voted in a poll, the systems usually have no way to tell explicitly who really received the invitation.

Shared Drive

(➡/⇌,⏱, 📍/🐾,🔧,📝,d:100000000,e:1,p:250,(fi))

Depending on who has write access to a shared drive, the sharing of information can be either uni- or bi-directional. With find grained access control, files can be shared privately between individuals or with a whole group of users. Full text search is possible on both, the server and the client side but there is usually no convenient way to tell who accessed which information.

Document Management

(🡒/⇌,⏱,📍/🐾,🔍,🖹/☑,d:100000000,e:1,p:1500000,(de,fi,gr,ta,te))

DMSs share many characteristics with shared drives but are implemented as web applications. A major difference is the availability of automated workflows, which allow the reception of information to be explicitly confirmed.

Appendix C

Interview Data

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
001	AK BG Sitzung	s	b	e		r	au,gr,te,vi	15	12	10000
002	AK Baugruppen Besprechung	s	b	e	g	r	au,gr,te	10	11	10000
003	AK Industrie Besprechung	s	b	e	g	r	au,gr,te	10	11	10000
004	AK bezogene Zusatzinformationen		b	e	p		te,au,vi		3	10000
005	Abgleich experimenteller und simulierter Ergebnisse	s	b		p	r	au		2	10000
006	Abklären von Verwaltungsvorgängen		b						2	100
007	Abklärung bez. Wälzkontakt	s	b		g		au		2	10000
008	Abklärung der Vernetzung, Schnittstellen, Aufgabengebiete		b		g		te,gr,ta		2	10000
009	Abrufen von hinterlegtem SFB Wissen		u				te,gr,ta		2	10000
010	Absprache zur Profilgeometrie		b		g	r			3	1000
011	Abstimmung		b	e	p	r	te,au,vi	14	15	10000
012	Abstimmung Begehungsvortrag		b						2	10000
013	Abstimmung Fertigungsrestriktionen	s	b	e					10	10000
014	Abstimmung Präsentation Begehung		b						11	10000
015	Abstimmung Zielfunktion & Nebenbedingungen	s	b	e					4	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
016	Abstimmung der Anlagennutzung		b		p		te,au		2	100
017	Abstimmung der Antragsinhalte	s	b		p	r	gr,ta,au		4	10000
018	Abstimmung der Benennung	s	b		g		au,te		2	1
019	Abstimmung der Darstellung von Prozessen	s	b		g		au,vi,gr		2	1
020	Abstimmung von Projektinhalten		b						3	10000
021	Abstimmung zwischen Teilprojekten	s	b			r			2	1000
022	Abstimmung über strategische und operative Fragen	s	b	e	p	r	te,au,vi	12	13	10000
023	Aktueller Stand		u				te,ta,gr		3	10000
024	Allgemeine Aufgaben		b				te,ta,gr		3	10000
025	Allgemeine Informationen		u	e	p	r	te,au,vi		21	10000
026	Allgemeine Informationen	a	u	e	p	r	te,ta		15	10000
027	Allgemeine Informationen		u	e	p	r	te,ta,au,vi		13	10000
028	Allgemeine Protokolle	a	u		g	r	te		2	10000
029	Allgemeine Strategische Mitteilungen	a	u	e	p	r	te,ta		31	10000
030	Anfordern von Proben		u		g		te		2	100
031	Animation für Messeauftritt		b				gr,te		11	10000
032	Antragsinhalte	a	u		p				2	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
033	Anwendungsbeispiel & Bauteilprüfung		b				ta,fi,gr,te		2	10000
034	Anwendungsideen		b			r	au,vi,gr,te		2	10000
035	Arbeitsauftrag Homepage		b	e			te,gr,vi		2	1
036	Aufgabenbezogene Zusatzinformationen		b	e	p		te,au,vi		2	10000
037	Aufgabenfindung		b		g		au,vi,te		11	10000
038	Aufgabenspzifische Anfrage		b				te,fi,ta,gr		2	10000
039	Aufgabenverteilung		b	e	g	r	ta,te	25	21	10000
040	Aufgabenverteilung		u	e	g		au		2	100
041	Aufgabenverteilung	a	u		g	r	au,te		2	10000
042	Aufgabenverteilung und -koordination	s	b		p		au		2	100
043	Aufgabenzuweisung und Rückmeldung		b	e	p		te,au,vi	2	2	10000
044	Ausarbeiten des Optimierungsmodells		b			r			2	10000
045	Ausarbeitung Antrag, Plakate, Grafiken, Demonstratoren	a	b		p	r	te,gr,ta,fi		2	100
046	Ausarbeitung der Veröffentlichung		b		p	r	te,ta,gr	2	2	1000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
047	Austausch allgemeiner Materialkennwerte von Spaltprofile und Spaltbiegeprofilen		b			r	te,ta		2	100
048	Austausch der Methoden / Vorgehensweise	s	b		g	r	au,te,vi.gr		3	1
049	Austausch der experimentellen und simulierten Ergebnisse		b		p	r	gr,te,ta		2	10000
050	Austausch von CAD Dateien für 3D Modelle		b				ph,fi		2	10000
051	Austausch von Daten zu Präsentationszwecken		b		g	r	gr,te,vi,fi		2	10000
052	Austausch von Simulationsmodellen		b		g	r	te,fi,au		2	10000
053	Austausch von Technologieinformationen zum Spaltprofilieren		b		g				2	1000
054	Austausch zu Gestaltunghinweisen		b		g	r	sd,ta,te		2	10000
055	Austausch zur Lösungsfindung	s	b		g	r	te,ta,gr,au		31	10000
056	Austausch zur Representation der TP	s	b		g	r	te,ta,sd,au,vi		31	10000
057	Austausch über Erfahrungen, Zielsetzungen und mögl. Verknüpfungen	s	b		g	r	te,de		11	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
058	Austausch über Möglichkeiten der Funktionsintegration	s	b	e	g	r	te,gr,ta,au,vi,sd		3	10000
059	Austausch über Technologieanforderungen		u				te,ta,au,vi		2	100
060	Auswahl Zielfunktion & Nebenbedingungen	a	u		g	r			7	10000
061	Auswertungsmethoden	a	b	e	p	r	ta,te		2	10000
062	Auswirkungen der Eigenspannungen auf den Zerspanungsprozess		b		p	r	gr,ta,te		2	10000
063	Bauteilanalyse Wälzverschleiß	a	b	e	g	r	te,gr,ta		2	10000
064	Bauteile für Werkstoffuntersuchung	s	u	e	g		ph		7	10000
065	Bauteile und erste Diskussion	s	b		p	r	ph,au		2	10000
066	Bauteileigenschaften	a	b	e	g	r	te,ta,gr		10	10000
067	Bauteileigenschaften	a	b	e	g	r	ta,gr,te		3	10000
068	Bearbeitete Proben		u		p		ph		1	10000
069	Bereitstellen Fertigungsrestriktionen	a	u		g	r			8	10000
070	Bereitstellung von Probenmaterial	a	b		g	r	te,ph,au		2	10000
071	Bericht über aktuelle Ergebnisse		u			r	tr,gr,vi,gr		31	10000
072	Berichte aus den AKs	s	b		g		te,gr		11	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
073	Beschreibung der Freiformfläche	a	b	e		r	fi,gr		2	10000
074	Besprechung AK Baugruppen	s	b	e	g	r	au,gr,te	15	11	10000
075	Besprechung Prozessparameter Spaltbiegen	s	b				te,gr		3	1000
076	Besprechung der Auswirkungen Nitrieren auf Wälzverschleis	s	b				au,vi,te,ta	3	3	10000
077	Besprechung der Gestalt der tiefgezogenen verzweigten Blechbauteile		b				au,gr		2	100
078	Besprechung der Wälzprozessdetails	s	b			r	au,vi,te,ta		2	10000
079	Besprechung zur Projektvorlesung	s	b	e	g	r	au,vi	20	31	10000
080	Besprechungsvorbereitungen	s	b	e	p		au,vi	2	2	100
081	Betreuung von Studentischen Arbeiten		b		p		au,te,sd,fi		8	10000
082	Bewertung der Proben	s	u		g	r	te,ta,gr		2	10000
083	Bibliographische Daten	a	b			r	te		2	10000
084	Brainstormings / Feedback	s	b		p	t	gr,te,au,vi		2	100
085	CAD Sollgeometrie		u			r	fi		2	10000
086	CAD-Modell Parametrisierung		b				fi		2	10000
087	Daten zum Wälzkontakt	a	u		g		te,ta,gr		2	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
088	Definition Beschreibungsstandard Produkt Eigenschaften		b		g	r	te, gr, sd		2	1
089	Definition der Beschreibung	a					fi		3	10000
090	Definition der Funktionsflächen, der Ersatzmodelle und des Bauraum		u		g	r	gr,ta,sd		3	10000
091	Definition der Schnittstellen		u		g	r	te		3	10000
092	Definition der benötigten Versuchsparamter	s	u		p		au		2	1000
093	Definition und Absprache von Aufgaben	s	b	e	g	r	te,au,gr		21	10000
094	Demonstratorentwicklung AK FL		b		g	r	au,te,gr,fi,vi		12	10000
095	Detailanstimmung der Anwendungsidee	s	b						3	10000
096	Diskussion der Ergebnisse	s	b		g		au,te,gr,vi,fi		2	10000
097	Diskussion der Ergebnisse	s	b		p		au,vi,te,gr		3	10000
098	Diskussion der Werkstoff Ergebnisse	s	b		p		au,gr,ta,te		4	10000
099	Diskussion der experimentellen und numerischen Ergebnisse der Lebensdauerbewertung		b	e	p		gr,ta,te,vi		2	1000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
100	Diskussion der verschiedenen experimentellen und numerischen Ergebnisse		b	e	p		gr,ta,te,vi		2	10000
101	Diskussion des Demonstratorkonzepts	s	b			r	au,te,gr	10	11	10000
102	Diskussion konkreter Probleme	s	b		p	r	au,vi		3	1
103	Dringende Terminabsprache	s	b		p				2	10000
104	Eigenspannungsverteilung im Ausgangsbauteil	a	u		p	r	gr,ta,te		2	10000
105	Eigenspannungsverteilung im zerspanten Bauteil	a	u			r	gr,ta,te		2	10000
106	Einbringen von Technologie Know-How zur Demonstratorerstellung	s	b	e	g	r	au,vi,te,gr,ta		11	10000
107	Eingangsgrößen für die Simulation		b		p	r	ta		2	10000
108	Einspeisen von Anwendungsbeispielen		u	e			te,gr,ta		2	10000
109	Entscheidungen	a	b		o	r	de		2	100
110	Entscheidungen		b	e	p	r	te,au,vi	12	13	10000
111	Entscheidungen		b			r	de,vi,au,te,gr		2	10000
112	Entwicklung von Ersatzmodellen		b		g	r	te,sd,ta		3	1
113	Erfasste Anforderungen	a	u		g	r	sd		3	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
114	Ergebnisse der Umformsimulation		b	e	p	r	gr,ta,te		2	1000
115	Ergebnisse der Werkstoffuntersuchung		b			r	gr,ta		7	10000
116	Ergebnisse der Wälzverschleistests an nichtnitrieren Spaltprofilen		b			r	te,ta		2	100
117	Erkenntnisse zur Werkzeugentwicklung		u		p	r	te,gr,ta,vi		2	100
118	Erläuterung der Projektinhalte	s	b		g	r	au,vi		3	10000
119	Erste Festlegung der Zielanwendungsideen	s	b						3	10000
120	Erstellen von Präsentationen	s	b		g		te,gr,au		2	100
121	Erstellung virtueller Demonstrator	a	b		g	r	te		2	10000
122	Fachliche Anfragen		b		g		te,gr,fi		2	10000
123	Fachlicher Informationsaustausch	s	b		g		au,te,gr,fi		2	10000
124	Fachlicher austausch über Methoden		b			r			2	100
125	Fachliches Rahmenwerk zu Anforderungen	a	u		p	r	te,fi		2	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
126	Fertigungsmöglichkeiten / Restriktionen		b		g	r	te,gr,fi,ta,sd		7	10000
127	Fertigungsrandbedingungen	a	u		g	r	ta,te		7	10000
128	Fertigungsrestriktionen		b		p	r	te,au,vi		2	10000
129	Fertigungsrestriktionen und Halbzeuge		u			r	ph,te,ta		2	10000
130	Fertigungsrestriktionen und Halbzeuge		u			r	ph,te,ta		3	10000
131	Fertigungsrestriktionen und Toleranzen		u		g	r	gr,ta,te		7	10000
132	Festlegung des Anwendungsbeispiels	s	b	e		r	au,vi,te,gr,ta		11	10000
133	Finanzen	a	b	e	g	r	ta,te		32	10000
134	Finanzfragen	s	b	e	p		au,vi	2	2	100
135	Finanzfragen / Abrechnung	s	b		p				4	10000
136	Finanzielles / Anschaffung	a	b			r			2	1000
137	Finanzielles / Anschaffungen	a	b		g	r			2	1000
138	Flanschverlauf und Zielgeometrie	a	u		p	r	gr,ta		2	100
139	Fließkurven / Materialeigenschaften		u			r	ta		2	10000
140	Fließkurven der Zugproben		u		g	r	ta		2	10000
141	Flurfunk	s	b		o	t	au		2	100

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
142	Formalisierte Entwicklungsaufgabe		b		g	r	fi,te,gr,ta,sd		2	10000
143	Formeller Projektfortschritt	a	u		g		te		2	1000
144	Gemeinsame Betreuung einer Studentischen Arbeit		b	e	p	r	te,au		2	100
145	Gemeinsame Veröffentlichung	a	u		w	r	te,gr,ta		1000000003	10000
146	Gemeinsame Veröffentlichung	a	u		w	r	te,gr,ta		1000000003	10000
147	Gemeinsame Veröffentlichung	a	u		w	r	te,gr,ta		1000000002	10000
148	Gemeinsame Veröffentlichung	a	u		w	r	te,ta,gr		1000000007	10000
149	Gemeinsame Veröffentlichung	a	u		w	r	te,ta,gr		1000000002	10000
150	Geometriedatenaustausch zu flächigen Bauteilen		b		g	r	ta,fi		2	100
151	Geometrienebenbedingungen		b			r	te		3	10000
152	Geometrienebenbedingungen (falls direkt verarbeitbar)		b				fi		2	100
153	Geometrierestriktionen								6	10000
154	Geänderte Materialeigenschaften		u		g	r	ta,gr		3	10000
155	Glossar		u		g	r	te		32	10000
156	Grenzen Funktionsintegration	a	u		g	r	te,ta		3	10000
157	Gruppensitzung AFBG	s	b	e	g	r	au,vi,te,gr		11	10000
158	Gruppensitzung AKF	s	b	e	g	r	au,vi,te,gr		11	10000
159	Hilfestellung zur Modellierung		b		g		fi,te,au		2	100

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
160	Hinweise zur Klärung auf Prof. Ebene	a	b		p				2	10000
161	Ideenaustausch	s	b		p	t	au,gr		2	1
162	Information zum aktuellen Stand		u	e			te,gr,vi,ta		31	10000
163	Informationen für den Webauftritt		u	e			te,gr,vi		5	10000
164	Informationen zum Eigenspannungszustand im Spaltprofil	a	u		g	r	te,gr,ta		2	10000
165	Informationen zum aktuellen Stand		u	e		r	te,gr,ta,fi,vi		11	10000
166	Informationen über technologieinduzierte Eigenschaften		b		g	r	te,gr,fi,ta,sd		7	10000
167	Informations Bedarf & Output		b		p		au		2	10000
168	Informationsverteilung		u				te,au,ta,da		2	10000
169	Inhaltliche Abstimmung der Veröffentlichung und gemeinsames Bearbeiten	s	b		p	r	te,gr	3	2	10000
170	Inhaltliche Kommunikation / Fachliche Fragen	s	b						2	1000
171	Inhaltliche Rückmeldung		b	e	p		te,au,vi		3	10000
172	Inhaltlicher Austausch		b		g	r	te,ta,fi,au		2	10000
173	Inhlatliche Diskussion und Beratung	s	b		g		gr,au,vi		2	1000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
174	Input Definition		b		p		au		2	10000
175	Integration von im Produktkontext nutzbaren Funktionen	s	u		g	r	te,gr,ta		11	10000
176	Klärung der Optimierungsmöglichkeiten		b			r	te,ta,gr		2	10000
177	Kommunikation Inhalte der Vorlesung		b		g		te,gr		2	10000
178	Konkretisierung der Anwendungsideen, Anforderungen und Randbedingungen		b			r			3	10000
179	Koordination Demonstrator FL	s	b	e	g	r	te,gr,ta,fi,sd,au	15	11	10000
180	Koordination Domonstrator BG	s	b	e	g	r	te,gr,ta,fi,sd,au	15	11	10000
181	Koordination MAB		b	e	g	r	te,da		3	10000
182	Koordination Workshops		b	e	g	r	te,da		3	10000
183	Koordination ausserfachlicher Aktivitäten		b		g		te,au		21	10000
184	Koordination der Anlagenbelegung und Resourcen	a	u		g	r	ta		2	1000
185	Koordination der Antragsstellung	a	b	e	p	r	te,gr	2	2	1000
186	Koordination der Bauteilweitergabe		b		p		te,au		2	1000
187	Koordination der Fertigungsanlage	a	b		g	r	da,te,ta		3	1000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
188	Koordination der Versuche		b		g		au,te		2	1000
189	Koordination der Veröffentlichungskorrektur		b						2	1000
190	Koordination der Zielsetzung der TP	s	b	e	g	r	te,gr,au,vi		31	10000
191	Koordination der Übung		b		g		te,da,fi,au		2	10000
192	Koordination des Antrags		b		g		te,gr		2	100
193	Koordination gemeinsamer Veröffentlichung		b		g		te,gr,au		2	100
194	Koordination von Veröffentlichungen		b		g		te,gr		2	100
195	Koordinierung der Vorträge Ziel 4	s	b				au,vi,te,gr		4	10000
196	Kovertierte Datenstruktur Freiformfläche		b		p		fi		2	1
197	LAS	s	b	e	g	r	au,vi,te,gr,ta	12	11	10000
198	LAS	s	b	e	g	r	te,gr,ta,au,vi		13	10000
199	LAS	s	b	e	g	r	te,gr,au,vi		17	10000
200	LAS	s	b	e	g	r	au,vi,te,gr,ta	12	13	10000
201	LBF Interne Präsentation	s	u				te,gr		21	1000
202	MAB	s	b	e	g	r	au,gr,te	30	34	10000
203	MAB	s	b	e	g	r	au,gr,te	30	31	10000
204	MAB	s	b	e	g	r	au,gr,te	30	31	10000
205	MAB	s	b	e	g	r	au,gr,te	30	31	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
206	Materialkennwerte		u		g	r	te		2	100
207	Matrialeigenschaften (UFG Flanschbereich)		u			r	te,ta,gr		2	10000
208	Maßhaltigkeit, Gratausprägung, Maßabweichungen		u	e	p	r	gr,te,ta		3	1000
209	Methoden und Modelle		b		g		fi,te,gr,sd		2	1
210	Nebenbedingungen, Zielfunktionen, Bauraumbeschränkungen	a	u		g	r	te		3	10000
211	Nitriertes Probenmaterial		u				ph		2	10000
212	Operative Entscheidungen und Maßnahmen	s	b	e	p		au,vi	2	2	100
213	Operative Mitteilungen		u	e	p	r	te,au,vi		21	10000
214	Optimale Prozessparameter Zerspanung		b	e	p	r	au,gr,vi,ta,te		3	1000
215	Optimale Steuerkurven		u			r	fi		2	10000
216	Optimale Technologieparameter für das Werkzeug		u		g	r	au,te		2	100
217	Optimierte Geometrie		u		g	r	gr,ta		3	10000
218	Optimierungsergebnisse Einzelteil								2	10000
219	Organisatorische Absprache und Finanzen		b	e	p	r	te,ta		3	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
220	Organisatorische Absprache und Finanzen			e	g	r	ta,te,au		3	1
221	Organisatorische Absprachen		b	e	g		au,te,da		2	10000
222	Organisatorische Absprachen	s	b	e	g	r	da,te,au		21	10000
223	Organisatorische Absprachen	s	b		g	r	au		2	10000
224	Organisatorische Informationen	a	u		g	r	te		32	10000
225	Organisatorisches	a	u	e					2	10000
226	Organisatorisches		b		g				2	10000
227	Organisatorisches	a	b	e	g	r	da,te		2	10000
228	Organisatorisches LBF		b		g	r			2	1000
229	Output Beispiele				p	r	te,gr,ta		2	10000
230	Parameter von flächigen Bauteilen bei der Anforderungserfassung	s	b		p		au,gr,vi		2	10000
231	Personalfragen	s	b		p		au		2	1000
232	Planung der Veröffentlichung	a	b		p	r	te,gr,ta		2	10000
233	Planung des Messeauftritts Hannover		b	e				3	11	10000
234	Planung des Vortrages	s	b		g		au,te,gr,vi		2	10000
235	Planung gemeinsamer Veröffentlichungen		b		g		te,gr,fi		2	10000
236	Planung gemeinsamer Veröffentlichungen		b		g		te,gr,au		2	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
237	Planung gemeinsamer Veröffentlichungen		b		g		te,gr,au		2	10000
238	Probenaustausch	s	b		g	r	ph,au		3	10000
239	Probenaustausch zur Bewertung	s	u		g	r	ph,au,vi		2	10000
240	Probenaustausch zur spanenden Bearbeitung		b		g		ph		2	100
241	Probenmaterial Spaltgebogen & Spaltprofiliert		u				ph		3	10000
242	Produktanforderungen		b	e	g	r	ta, gr		2	1
243	Produktbeispiele		b		g	r	te, gr, fi, ta		16	10000
244	Produktgeometriedaten		b	e	g	r	fi,gr		2	1000
245	Produktideen und Wirkprinzipien/Lösungselemente		b		g	r	gr,ta,te		2	1
246	Projektfortschritt / Probleme	s	b		g		au		2	1000
247	Projektkoordination	s	b		p	r	te,gr,au		2	1
248	Projektplanung		b	e	g		te,da		2	10000
249	Projektplanung	s	b		g	r	te,da,de		31	10000
250	Projektplanung und Zielplanung	s	b		p	r	au,te,gr		2	1
251	Projektvorlesung	s	b	e			te,gr,ta,au,vi,ph	20	21	10000
252	Protokolle	a	u		g	r	te,ta		2	10000
253	Prozessdarstellung		u		g	r	te,gr		2	1
254	Prozessparamter der Bauteilherstellung	a	u	e	g	r	ta		9	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
255	Präsentation der Ergebisse	s	b		g		te,gr,au,vi		32	10000
256	Präsentation der Projektergebnisse	s	b		g		te,gr,vi,au		31	10000
257	Prüfung der Reslisierbarkeit der Anwendungsidee		b			r	te,ta,fi		2	10000
258	Punkte der Freiformfläche		b		p		fi		2	10000
259	Randbedingungen zur Maschinenleistung		u		g	r	ta,sd		2	1000
260	Randbedingunger der Versuchsdurchführung		b		p	r	te,au,ta		2	10000
261	Redaktion Tagungsband	a	b			r	te,gr		2	10000
262	Reflexion der Arbeitsweise	s	b		p		au,te,gr		2	100
263	Richtlinien für Versuche		b	e	p	r	ta,te		2	10000
264	Rohmaterial zur Probenherstellung		u		g	r	ph		3	10000
265	Rückfragen zum SFB oder TP		b			r	te,ta,gr,au		3	10000
266	Rückfragen zum SFB oder TP		b			r	te,au		2	10000
267	Rückmeldung Bauteilqualität	s	b		p		au		2	1000
268	Rückmeldung zu aufgetragenen Aufgaben		b	e	p		te,au,vi		2	10000
269	Rückmeldung über Übertragbarkeit auf Schienenfräsen		u		p	r	te,gr		2	100

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
270	Rücksprache zur Anlagen- und Resourcenbelegung		b		p		te,au		2	1000
271	SFB Ausflug		b	e	g	r	te,da		32	10000
272	SFB Workshop	s	b	e	g	r	au,vi,te,gr,ta	35	2	10000
273	Schnittstellen Definition		b		g	r	te,gr,fi,sd,ta		2	10000
274	Simulationsmodell Tiefziehen	a	u			r	sd		2	10000
275	Sitzungsvorbereitungen		b	e	p	r	te,ta,gr	2	2	100
276	Sollgeometrie	a	u			r	fi		2	100
277	Spezifikation der Linearführung		u		g		gr,te		2	10000
278	Statische Werkstoffeigenschaften und Gefüge		u	e	g	r	gr,ta		2	10000
279	Strategische Entscheidungen und Maßnahmen	s	b	e	p		au,vi	2	2	100
280	Strategische Mitteilungen		u	e	p	r			15	10000
281	Technologie- und Wissenstransfer	a	u		g	r	au,te,gr,ta		3	1
282	Terminabsprache		b	e			da,te		31	10000
283	Terminabsprache		b		p				2	10000
284	Terminabsprache	a	b		p		da		2	10000
285	Terminabsprache AK Baugruppen		b		p	r	da		2	10000
286	Terminabsprache AK Industrie		b		p	r	da		2	10000
287	Terminabsprache MAB		u				da		32	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
288	Terminabsprache Professoren		b				da		15	10000
289	Terminabsprachen		b	e			da,te		11	10000
290	Terminabsprachen	s	b	e	p		da		3	100
291	Terminabsprachen alle	a	b	e	g		da		31	10000
292	Terminabsprachen einzelne	a	b	e	p		da		2	10000
293	Terminabstimmung	a	b		g	r	da,te		3	10000
294	Terminabstimmung		b				da		12	10000
295	Terminabstimmung	a	b		g	r	da,te		11	10000
296	Terminabstimmung	a	b		g	r	da,te		11	10000
297	Termine	a	u	e	g	r	da,te		2	10000
298	Terminfindung	a	b	e	g	r	da,te		31	10000
299	Terminfindung	a	b	e	g	r	da,te	25	21	10000
300	Terminfindung	a	b	e	g	r	da,te		11	10000
301	Terminfindung	a	b	e	p	r	da,te	14	15	10000
302	Terminkoordination	a	u		p		da,te		2	1
303	Terminkoordination SFB		u		g	r	da		36	10000
304	Terminmitteilung		u		g	r	da,te		3	10000
305	Terminmitteilung	a	u	e	g	r	da,te		2	10000
306	Terminplanung		u	e		r	da,te		2	1
307	Uebergabe des Werkzeugs		u		g	r	ph,au,te		2	100
308	Uebergabe von Daten und Proben		u		g	r	ph,te		2	100

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
309	Uebergabe von Daten und Proben		u		g	r	te,ph		2	1000
310	Ursachenuntersuchung von rißbehafteten Bauteilen	a	b		p	r	te,gr,ph		2	10000
311	Vailiderung der Simulationsergebnisse	s	b		p	r	ph,fi,au,vi		2	10000
312	Verbesserte Nitriereigenschaften		u				te,ta		2	10000
313	Verbesserung durch Optimierung	a	u						6	10000
314	Verfahrensgrenzen der HSC Bearbeitung	a	u	e	p		ta,gr,te		3	10000
315	Verfahrensgrenzen zur spanenden Herstellung von Flanschhöhen	a	b		p		te,ta,gr		2	100
316	Veröffentlichung	a	u		w	r	te,gr		1000000002	10000
317	Veröffentlichung	a	u		w	r	te,gr,ta		1000000002	10000
318	Veröffentlichung der Ergebnisse	a	u		w	r	te,gr,ta		1000000003	10000
319	Veröffentlichung der Ergebnisse	a	u		w	r	te,gr,ta		1000000001	10000
320	Veröffentlichung von Erkenntnissen	a			w		te,gr,ta		1000000001	10000
321	Veröffentlichungen und Anträge	s	b		p		te,gr,au,vi		2	1000
322	Veröffentlichungsspezifische Informationen		b		p	r	te,gr,ta	3	7	10000
323	Vollversammlung	s	b	e	g	r	au,gr,te	40	41	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
324	Vollversammlung	s	b	e	g	r	au,gr,te	40	42	10000
325	Vorbereitung Projektvorlesung		b			r	sd,te		2	100
326	Vorbereitung und Korrektur Übung Ringvorlesung	s	b		p	r	au,te,gr		2	1
327	Vorlagen	a	b		g	r	fi,gr		2	10000
328	Weiterentwicklung der HSC Bearbeitungsmodule (Antriebe, Profilführung, ...)	a	u		p	r	te,ta,gr,vi		3	1000
329	Weitergabe der Bauteile	a	u		g	r	ph		2	1000
330	Weitergabe der Metadaten von Veröffentlichungen	a	b	e	g		te		2	10000
331	Weitergabe von Proben	s	u		g	r	ph,au		2	10000
332	Werkstoffdaten	a	u		g	r			2	10000
333	Werkstoffdatenbank	a	u	e	g	r	ta		2	10000
334	Werkstoffeigenschaften		u						3	10000
335	Werkstoffkennwerte		b	e	p	r	gr,ta		2	1000
336	Werkstoffkennwerte		b	e	p	r	gr,ta		2	10000
337	Werkstoffproben		u		g		ph		2	100
338	Werkstoffproben	s	u	e			ph		2	10000
339	Werkstoffrestriktionen und Potentiale	a	u		g	r	te,ta		7	10000
340	Werkzeug-Mschinenschnittstelle		b		g	r	au,te		2	100
341	Wiss. Koordination zwischen TP		b	e	p		te,au,vi	25	21	10000

Continued on next page

Table C.1 – *Continued from previous page*

ID	Conversation	Sync.	Dir.	Rec.	Vis.	Repr.	Cont.	eMult.	pMult.	Dist.
342	Wälzbeanspruchtes Probenmaterial		u				ph		2	10000
343	Wälzverschleißbauteile und erste Diskussion	s	b		p	r	ph,au		2	10000
344	Zerspante Werkstückproben		u		p		ph,te,ta		2	10000
345	Zerspanungswerkzeuge		u		p	r	ph,te,ta		3	1000
346	Zusammenfassung der Ergebnisse	a	b		g	r	te,gr	30	31	10000
347	Zusammenführen der Ergebnisse		b		p		te,gr,au		2	10000
348	Zusammengeführte Ergebnisse Wälzfestigkeit		b	e	g	r	gr,ta,te,vi		32	10000
349	Zusammengeführte Werkstoff Ergebnisse	a	b			r	gr,ta,te,vi		32	10000
350	Zusammengeführte experimentelle und numerische Eregebnisse der Lebensdauerbewertung		b	e	g	r	gr,ta,te,vi		32	10000
351	Zyklische Werkstoffkennwerte (Dehnungswöhlerlinien Diagramme)	s	b		p	r	ta,te,gr		3	1000

Table C.1: Complete list of conversations at CRC666

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
001	.278	.306	.278	.389	.500	.330	.044	.211	.267	.434	.386
002	.259	.296	.370	.370	.481	.440	.028	.296	.361	.515	.486
003	.259	.296	.370	.370	.481	.440	.028	.296	.361	.515	.486
004	.074	.185	.074	.185	.296	.069	.028	.074	.139	.407	.115
005	.222	.222	.222	.222	.333	.139	.028	.111	.250	.444	.111
006	0	0	0	0	.111	0	0	0	.111	.111	.0
007	.222	.222	.333	.222	.333	.139	.028	.111	.250	.444	.111
008	0	.074	.111	0	.111	.139	.028	.222	.250	.222	.222
009	0	.185	.111	.111	0	.139	.139	.222	.028	0	.222
010	0	0	.111	0	.111	.263	0	.222	.333	.222	.263
011	.185	.185	.185	.296	.407	.333	.042	.199	.264	.451	.379
012	0	0	0	0	.111	.028	.028	0	.139	.111	.0
013	.111	.222	.111	.222	.333	.105	.028	0	.139	.333	.078
014	0	0	0	0	.111	.107	.028	0	.139	.111	.079
015	.111	.222	.111	.222	.333	.083	.028	0	.139	.333	.056
016	.056	.056	.056	.056	.167	0	0	.056	.111	.278	.056
017	.148	.222	.148	.148	.259	.194	.028	.185	.250	.370	.241
018	.167	.167	.278	.167	.278	.111	0	.167	.222	.389	.167
019	.185	.222	.296	.185	.296	.111	0	.185	.222	.407	.185
020	0	0	0	0	.111	.069	.028	0	.139	.111	.041
021	.111	.111	.111	.111	.222	.111	0	.111	.222	.222	.111
022	.296	.296	.296	.407	.519	.331	.036	.193	.258	.558	.377
email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)											

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
023	0	.185	.111	.111	0	.180	.139	.222	.028	0	.263
024	0	.074	0	0	.111	.069	.028	.111	.139	.111	.152
025	.074	.296	.185	.296	.185	.336	.139	.296	.139	.296	.382
026	0	.278	.111	.222	.111	.444	.250	.444	.250	.222	.527
027	.056	.306	.167	.278	.167	.331	.139	.306	.139	.278	.387
028	0	.111	.222	.111	0	.472	.250	.556	.361	.111	.556
029	0	.278	.111	.222	.111	.450	.250	.444	.250	.222	.533
030	0	.111	.222	.111	0	.222	.111	.333	.111	.111	.333
031	0	.056	0	0	.111	.107	.028	.111	.139	.111	.190
032	0	.111	.111	.111	0	.250	.250	.222	.139	.111	.222
033	0	.083	0	0	.111	.056	.056	.111	.167	.139	.111
034	.056	.083	.056	.056	.167	.139	.028	.194	.250	.167	.194
035	.037	.185	.037	.148	.259	0	0	.111	.111	.259	.111
036	.074	.185	.074	.185	.296	.028	.028	.074	.139	.407	.074
037	.074	.074	.185	.074	.185	.218	.028	.185	.250	.296	.264
038	0	.083	0	0	.111	.056	.056	.111	.167	.139	.111
039	.111	.333	.333	.333	.222	.222	.111	.222	.111	.333	.222
040	.111	.167	.222	.222	.333	.447	.059	.365	.393	.389	.530
041	.056	.167	.278	.167	.056	.472	.250	.500	.361	.167	.500
042	.222	.222	.222	.222	.333	0	0	0	.111	.444	.0
043	.185	.185	.185	.296	.407	.139	.028	.074	.139	.407	.185
email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)											

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
044	0	0	0	0	.111	.139	.028	.111	.250	.111	.111
045	0	.083	0	0	.111	.250	.139	.333	.361	.250	.333
046	.111	.074	.111	.111	.222	.222	0	.222	.222	.222	.333
047	0	.056	0	0	.111	.111	0	.222	.222	.111	.222
048	.185	.185	.296	.185	.296	.300	.037	.296	.370	.407	.337
049	0	.074	0	0	.111	.139	.028	.222	.250	.222	.222
050	.056	.111	.056	.056	.167	.083	.083	.111	.194	.222	.111
051	.028	.083	.139	.028	.139	.278	.056	.333	.389	.278	.333
052	.037	.074	.148	.037	.148	.287	.065	.296	.398	.296	.296
053	0	0	.111	0	.111	.111	0	.111	.222	.222	.111
054	.037	.074	.148	.037	.148	.287	.065	.333	.398	.259	.333
055	.139	.194	.250	.139	.250	.339	.028	.306	.361	.361	.394
056	.178	.200	.289	.178	.289	.361	.050	.311	.383	.400	.400
057	.111	.111	.278	.167	.278	.385	.083	.333	.417	.389	.412
058	.167	.315	.278	.278	.389	.310	.046	.315	.380	.500	.356
059	.056	.194	.167	.167	.056	.111	.111	.194	0	.056	.194
060	0	.111	.222	.111	0	.544	.250	.444	.361	.111	.516
061	0	.167	0	.111	.222	.250	.139	.333	.361	.333	.333
062	0	.074	0	0	.111	.139	.028	.222	.250	.222	.222
063	0	.185	.111	.111	.222	.361	.139	.444	.472	.333	.444
064	.222	.444	.444	.444	.333	.322	.139	.333	.139	.444	.405

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
065	.222	.222	.222	.222	.333	.139	.028	.167	.250	.444	.167
066	0	.185	.111	.111	.222	.402	.139	.444	.472	.333	.485
067	0	.185	.111	.111	.222	.439	.139	.444	.472	.333	.522
068	.111	.222	.222	.222	.111	.139	.139	.222	.028	.222	.222
069	0	.111	.222	.111	0	.546	.250	.444	.361	.111	.519
070	.074	.074	.185	.074	.185	.361	.139	.407	.472	.296	.407
071	.074	.222	.185	.185	.074	.376	.176	.333	.176	.074	.422
072	.111	.167	.222	.111	.222	.218	.028	.222	.250	.333	.301
073	0	.222	0	.111	.222	.306	.194	.333	.417	.278	.333
074	.259	.296	.370	.370	.481	.440	.044	.313	.378	.527	.486
075	.111	.167	.111	.111	.222	.041	0	.111	.111	.222	.152
076	.278	.194	.278	.278	.389	.180	.028	.083	.139	.278	.235
077	.056	.111	.056	.056	.167	0	0	.056	.111	.167	.056
078	.167	.194	.167	.167	.278	.139	.028	.194	.250	.278	.194
079	.333	.333	.444	.444	.556	.450	.053	.303	.387	.607	.478
080	.333	.333	.333	.444	.556	.111	0	.056	.111	.556	.167
081	.056	.083	.056	.056	.167	.157	.083	.083	.194	.306	.157
082	.111	.296	.333	.222	.111	.361	.139	.444	.250	.222	.444
083	0	0	0	0	.111	.250	.139	.333	.361	.111	.333
084	.278	.306	.278	.278	.389	0	.111	.083	.111	.500	.083
085	0	.222	.111	.111	0	.361	.250	.333	.250	.111	.333

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
086	0	.111	0	0	.111	.139	.139	.111	.250	.222	.111
087	0	.185	.222	.111	0	.361	.250	.444	.250	.111	.444
088	.037	.074	.148	.037	.148	.259	.037	.333	.370	.259	.333
089	0	.111	0	0	0	.291	.250	.222	.250	.111	.263
090	.037	.222	.259	.148	.037	.439	.176	.444	.287	.148	.485
091	0	.111	.222	.111	0	.402	.139	.444	.250	.111	.485
092	.222	.333	.333	.333	.222	.111	.111	.111	0	.333	.111
093	.148	.296	.259	.259	.370	.336	.028	.296	.361	.481	.382
094	.044	.089	.156	.044	.156	.352	.050	.311	.383	.289	.391
095	.111	.111	.111	.111	.222	.069	.028	0	.139	.222	.041
096	.167	.194	.167	.167	.278	.069	.028	.083	.139	.389	.124
097	.156	.200	.267	.156	.267	.161	.050	.200	.272	.400	.200
098	.139	.194	.139	.139	.250	.083	.028	.083	.139	.361	.139
099	.028	.194	.028	.139	.250	0	0	.111	.111	.361	.111
100	.028	.194	.028	.139	.250	.028	.028	.111	.139	.361	.111
101	.259	.185	.259	.259	.370	.329	.028	.185	.250	.293	.375
102	.222	.222	.222	.222	.333	.152	0	.167	.222	.444	.208
103	.111	.111	.111	.111	.222	.028	.028	0	.139	.333	.0
104	0	.185	.111	.111	0	.361	.250	.444	.250	.111	.444
105	0	.185	.111	.111	0	.361	.250	.444	.250	0	.444
106	.156	.311	.267	.267	.378	.329	.028	.311	.361	.489	.390

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
107	0	.111	0	0	.111	.139	.028	.222	.250	.222	.222
108	0	.296	.111	.222	.111	.139	.139	.222	.028	.111	.222
109	.185	.185	.185	.296	.407	.331	.036	.193	.258	.447	.377
110	.111	0	.222	.222	.333	.333	.333	.444	.556	.333	.333
111	.044	.067	.067	.067	.178	.161	.050	.200	.272	.178	.200
112	.037	.074	.148	.037	.148	.300	.037	.333	.370	.259	.374
113	.111	.222	.333	.222	.111	.624	.361	.556	.472	.222	.597
114	0	.185	0	.111	.222	.111	0	.222	.222	.333	.222
115	0	.111	0	0	.111	.210	.028	.222	.250	.111	.294
116	0	.056	0	0	.111	.111	0	.222	.222	.111	.222
117	.028	.194	.139	.139	.028	.222	.111	.333	.111	.139	.333
118	.222	.222	.333	.222	.333	.291	.028	.278	.361	.444	.319
119	.111	.111	.111	.111	.222	.069	.028	0	.139	.222	.041
120	.148	.185	.259	.148	.259	.111	0	.185	.222	.370	.185
121	0	0	.111	0	.111	.361	.139	.444	.472	.222	.444
122	0	.074	.111	0	.111	.176	.065	.222	.287	.259	.222
123	.139	.194	.250	.139	.250	.167	.056	.194	.278	.389	.194
124	0	0	0	0	.111	.111	0	.111	.222	.111	.111
125	0	.167	.111	.111	0	.417	.306	.444	.306	.167	.444
126	.022	.089	.133	.022	.133	.366	.072	.333	.406	.267	.405
127	0	.167	.222	.111	0	.544	.250	.556	.361	.111	.627

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
128	.074	.074	.074	.074	.185	.139	.028	.185	.250	.296	.185
129	.037	.185	.148	.148	.037	.291	.139	.333	.139	.037	.374
130	.037	.185	.148	.148	.037	.250	.139	.333	.139	.037	.333
131	0	.185	.222	.111	0	.433	.139	.444	.250	.111	.516
132	.156	.311	.156	.267	.378	.218	.028	.200	.250	.378	.279
133	0	.167	.111	.111	.222	.450	.139	.444	.472	.333	.533
134	.333	.333	.333	.444	.556	.111	0	.056	.111	.556	.167
135	.111	.111	.111	.111	.222	.083	.028	0	.139	.333	.056
136	0	0	0	0	.111	.222	.111	.222	.333	.111	.222
137	0	0	.111	0	.111	.333	.111	.333	.444	.222	.333
138	0	.222	.111	.111	0	.333	.222	.444	.222	.111	.444
139	0	.222	.111	.111	0	.250	.139	.333	.139	0	.333
140	0	.222	.222	.111	0	.361	.139	.444	.250	.111	.444
141	.444	.333	.444	.444	.556	0	.222	.111	.222	.556	.0
142	.022	.089	.133	.022	.133	.294	.072	.333	.406	.267	.333
143	0	.111	.222	.111	0	.333	.222	.444	.222	.111	.444
144	.056	.167	.056	.167	.278	.111	0	.167	.222	.389	.167
145	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
146	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
147	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
148	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)											

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
149	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
150	0	.111	.111	0	.111	.278	.056	.333	.389	.278	.333
151	0	0	0	0	.111	.180	.028	.222	.250	.111	.263
152	0	.111	0	0	.111	.111	.111	.111	.222	.222	.111
153	0	0	0	0	0	.096	.028	0	.028	0	.068
154	0	.222	.222	.111	0	.402	.139	.444	.250	.111	.485
155	0	.111	.222	.111	0	.450	.139	.444	.250	.111	.533
156	0	.167	.222	.111	0	.513	.250	.556	.361	.111	.597
157	.167	.306	.278	.278	.389	.329	.028	.306	.361	.500	.385
158	.167	.306	.278	.278	.389	.329	.028	.306	.361	.500	.385
159	.037	.074	.148	.037	.148	.148	.037	.185	.259	.296	.185
160	0	0	0	0	.111	.139	.139	.111	.250	.222	.111
161	.278	.333	.278	.278	.389	0	.111	.056	.111	.500	.056
162	.028	.306	.139	.250	.139	.228	.139	.222	.028	.139	.311
163	.037	.296	.148	.259	.148	.202	.139	.222	.028	.148	.285
164	0	.185	.222	.111	0	.472	.250	.556	.361	.111	.556
165	.022	.311	.133	.244	.133	.351	.161	.333	.161	.156	.412
166	.022	.089	.133	.022	.133	.366	.072	.333	.406	.267	.405
167	.111	.111	.111	.111	.222	.028	.028	0	.139	.333	.0
168	.056	.167	.167	.167	.056	.167	.167	.194	.056	.056	.194
169	.222	.167	.222	.222	.333	.250	.028	.222	.250	.333	.333

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
170	.111	.111	.111	.111	.222	0	0	0	.111	.222	.0
171	.074	.185	.074	.185	.296	.069	.028	.074	.139	.407	.115
172	.028	.083	.139	.028	.139	.278	.056	.306	.389	.278	.306
173	.185	.222	.296	.185	.296	.111	0	.185	.222	.407	.185
174	.111	.111	.111	.111	.222	.028	.028	0	.139	.333	.0
175	.111	.296	.333	.222	.111	.440	.139	.444	.250	.222	.523
176	0	.074	0	0	.111	.139	.028	.222	.250	.111	.222
177	0	.056	.111	0	.111	.139	.028	.222	.250	.222	.222
178	0	0	0	0	.111	.180	.028	.111	.250	.111	.152
179	.259	.315	.370	.370	.481	.477	.081	.331	.415	.545	.505
180	.259	.315	.370	.370	.481	.477	.081	.331	.415	.545	.505
181	.056	.111	.167	.167	.278	.347	.083	.333	.417	.389	.374
182	.056	.111	.167	.167	.278	.347	.083	.333	.417	.389	.374
183	.056	.056	.167	.056	.167	.225	.028	.167	.250	.278	.252
184	0	.222	.222	.111	0	.444	.222	.556	.333	.111	.556
185	.111	.167	.111	.222	.333	.333	.111	.333	.333	.333	.444
186	.056	.056	.056	.056	.167	0	0	.056	.111	.278	.056
187	.037	.037	.148	.037	.148	.411	.148	.444	.481	.259	.485
188	.056	.056	.167	.056	.167	.111	0	.167	.222	.278	.167
189	0	0	0	0	.111	0	0	0	.111	.111	.0
190	.167	.306	.278	.278	.389	.339	.028	.306	.361	.500	.394

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
191	.056	.056	.167	.056	.167	.194	.083	.194	.306	.306	.194
192	0	.056	.111	0	.111	.111	0	.222	.222	.222	.222
193	.037	.074	.148	.037	.148	.111	0	.185	.222	.259	.185
194	0	.056	.111	0	.111	.111	0	.222	.222	.222	.222
195	.167	.194	.167	.167	.278	.083	.028	.083	.139	.278	.139
196	0	.111	0	0	.111	.111	.111	.111	.222	.333	.111
197	.267	.311	.378	.378	.489	.442	.036	.319	.369	.528	.503
198	.156	.311	.267	.267	.378	.331	.028	.311	.361	.489	.392
199	.267	.311	.378	.378	.489	.440	.036	.319	.369	.528	.501
200	.167	.306	.278	.278	.389	.334	.028	.306	.361	.500	.389
201	.111	.278	.222	.222	.111	.197	.111	.222	0	.111	.308
202	.259	.296	.370	.370	.481	.450	.064	.332	.397	.540	.496
203	.259	.296	.370	.370	.481	.450	.064	.332	.397	.540	.496
204	.259	.296	.370	.370	.481	.450	.064	.332	.397	.540	.496
205	.259	.296	.370	.370	.481	.450	.064	.332	.397	.540	.497
206	0	.111	.222	.111	0	.333	.111	.444	.222	.111	.444
207	0	.185	.111	.111	0	.250	.139	.333	.139	0	.333
208	0	.296	.111	.222	.111	.263	.111	.333	.111	.222	.374
209	.028	.083	.139	.028	.139	.167	.056	.222	.278	.278	.222
210	0	.111	.222	.111	0	.513	.250	.556	.361	.111	.597
211	.111	.222	.222	.222	.111	.139	.139	.222	.028	.111	.222

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
212	.333	.333	.333	.444	.556	.111	0	.056	.111	.556	.167
213	.074	.296	.185	.296	.185	.336	.139	.296	.139	.296	.382
214	.044	.200	.044	.156	.267	.152	0	.200	.222	.378	.241
215	0	.222	.111	.111	0	.361	.250	.333	.250	.111	.333
216	.056	.167	.278	.167	.056	.333	.111	.389	.222	.167	.389
217	0	.222	.222	.111	0	.402	.139	.444	.250	.111	.485
218	0	0	0	0	0	.028	.028	0	.028	0	.0
219	0	.167	0	.111	.222	.180	.028	.222	.250	.333	.263
220	.037	.185	.148	.148	.148	.263	0	.296	.222	.259	.337
221	.185	.259	.296	.296	.407	.373	.065	.296	.398	.519	.382
222	.074	.148	.185	.185	.296	.176	.065	.185	.287	.407	.185
223	.222	.222	.333	.222	.333	.250	.028	.222	.361	.444	.222
224	0	.111	.222	.111	0	.561	.250	.556	.361	.111	.644
225	0	0	.111	0	.111	.139	.028	.111	.250	.222	.111
226	0	.222	.111	.222	.111	.250	.250	.222	.139	.111	.222
227	.056	.111	.167	.167	.278	.417	.194	.444	.528	.389	.444
228	0	0	.111	0	.111	.222	0	.222	.333	.222	.222
229	0	.074	0	0	0	.139	.028	.222	.139	.111	.222
230	.185	.222	.185	.185	.296	.028	.028	.074	.139	.407	.074
231	.222	.222	.222	.222	.333	0	0	0	.111	.444	.0
232	.035	.156	.090	.082	.146	.357	.229	.415	.443	.222	.441
email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)											

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
233	.111	.111	.111	.222	.333	.218	.028	0	.139	.222	.190
234	.167	.194	.278	.167	.278	.139	.028	.194	.250	.389	.194
235	0	.074	.111	0	.111	.176	.065	.222	.287	.259	.222
236	.037	.074	.148	.037	.148	.139	.028	.185	.250	.259	.185
237	.037	.074	.148	.037	.148	.139	.028	.185	.250	.259	.185
238	.222	.222	.333	.222	.333	.291	.028	.278	.361	.444	.319
239	.222	.333	.444	.333	.222	.361	.139	.407	.250	.333	.407
240	.111	.111	.222	.111	.222	.111	0	.222	.222	.333	.222
241	.111	.222	.222	.222	.111	.180	.139	.222	.028	.111	.263
242	0	.222	.111	.111	.222	.222	0	.333	.333	.333	.333
243	0	.083	.111	0	.111	.361	.056	.333	.389	.250	.417
244	0	.222	.111	.111	.222	.278	.056	.333	.389	.389	.333
245	0	.074	.111	0	.111	.222	0	.333	.333	.222	.333
246	.222	.222	.333	.222	.333	.111	0	.111	.222	.444	.111
247	.148	.185	.148	.148	.259	.111	0	.185	.222	.370	.185
248	.056	.111	.167	.167	.278	.194	.083	.222	.306	.389	.222
249	.148	.111	.296	.185	.296	.413	.102	.333	.435	.407	.422
250	.148	.185	.148	.148	.259	.111	0	.185	.222	.370	.185
251	.278	.315	.278	.389	.500	.225	.053	.118	.165	.440	.290
252	0	.167	.222	.111	0	.472	.250	.556	.361	.111	.556
253	0	.167	.222	.111	0	.333	.111	.444	.222	.111	.444
email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)											

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
254	0	.333	.222	.222	.111	.548	.250	.556	.361	.222	.632
255	.167	.194	.278	.167	.278	.228	.028	.194	.250	.389	.283
256	.167	.194	.278	.167	.278	.228	.028	.194	.250	.389	.283
257	0	.074	0	0	.111	.176	.065	.222	.287	.148	.222
258	0	.111	0	0	.111	.139	.139	.111	.250	.333	.111
259	.056	.222	.278	.167	.056	.389	.167	.444	.278	.167	.444
260	.037	.074	.037	.037	.148	.139	.028	.185	.250	.259	.185
261	0	.056	0	0	.111	.250	.139	.333	.361	.111	.333
262	.148	.185	.148	.148	.259	0	0	.074	.111	.370	.074
263	0	.167	0	.111	.222	.139	.028	.222	.250	.333	.222
264	.111	.222	.333	.222	.111	.402	.139	.444	.250	.222	.485
265	.028	.083	.028	.028	.139	.180	.028	.194	.250	.139	.235
266	.056	.056	.056	.056	.167	.139	.028	.167	.250	.167	.167
267	.222	.222	.222	.222	.333	0	0	0	.111	.444	.0
268	.074	.185	.074	.185	.296	.028	.028	.074	.139	.407	.074
269	0	.167	.111	.111	0	.222	.111	.333	.111	.111	.333
270	.056	.056	.056	.056	.167	0	0	.056	.111	.278	.056
271	.056	.111	.167	.167	.278	.394	.083	.333	.417	.389	.422
272	.267	.311	.378	.378	.489	.361	.067	.350	.400	.550	.422
273	.022	.089	.133	.022	.133	.294	.072	.333	.406	.267	.333
274	.111	.222	.222	.222	.111	.472	.361	.444	.361	.111	.444

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
275	.111	.185	.111	.222	.333	.222	0	.222	.222	.333	.333
276	0	.222	.111	.111	0	.444	.333	.444	.333	.111	.444
277	0	.167	.222	.111	0	.250	.139	.333	.139	.111	.333
278	0	.333	.222	.222	.111	.361	.139	.444	.250	.222	.444
279	.333	.333	.333	.444	.556	.111	0	.056	.111	.556	.167
280	0	.222	.111	.222	.111	.333	.139	.222	.139	.222	.305
281	.028	.194	.250	.139	.028	.485	.222	.528	.333	.139	.569
282	.056	.111	.056	.167	.278	.172	.083	.111	.194	.278	.200
283	.111	0	.111	.111	.222	.250	.250	.222	.361	.333	.222
284	0	0	0	0	.111	.028	.028	0	.139	.222	.0
285	.111	0	.111	.111	.222	.250	.139	.222	.361	.333	.222
286	.111	0	.111	.111	.222	.250	.139	.222	.361	.333	.222
287	.111	.111	.222	.222	.111	.339	.250	.222	.139	.111	.311
288	.111	0	.111	.111	.222	.222	.139	.111	.250	.222	.194
289	.222	.222	.222	.333	.444	.152	.111	.111	.222	.556	.152
290	.056	.111	.056	.167	.278	.162	.083	.111	.194	.278	.190
291	.111	.111	.222	.222	.333	.450	.250	.333	.472	.444	.422
292	.111	.111	.111	.222	.333	.250	.250	.222	.361	.444	.222
293	.111	0	.111	.111	.222	.219	.139	.111	.250	.222	.191
294	.056	0	.167	.056	.167	.496	.194	.444	.528	.278	.523
295	.056	0	.167	.056	.167	.458	.194	.444	.528	.278	.485

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
296	.056	0	.167	.056	.167	.496	.194	.444	.528	.278	.523
297	.056	.222	.278	.278	.167	.528	.306	.556	.417	.278	.556
298	.167	.111	.167	.278	.389	.499	.209	.347	.431	.432	.527
299	.056	.111	.167	.167	.278	.496	.194	.444	.528	.389	.523
300	.056	.111	.167	.167	.278	.505	.194	.444	.528	.389	.533
301	.167	.111	.278	.278	.389	.614	.226	.476	.559	.444	.641
302	.056	.111	.167	.167	.056	.278	.278	.333	.167	.167	.333
303	.111	.111	.333	.222	.111	.562	.250	.444	.361	.222	.534
304	.056	.111	.278	.167	.056	.458	.194	.444	.306	.167	.485
305	.056	.222	.278	.278	.167	.528	.306	.556	.417	.278	.556
306	.056	.222	.167	.278	.167	.278	.167	.333	.167	.167	.333
307	.074	.185	.296	.185	.074	.333	.111	.407	.222	.185	.407
308	.056	.167	.278	.167	.056	.333	.111	.444	.222	.167	.444
309	.056	.167	.278	.167	.056	.333	.111	.444	.222	.167	.444
310	.037	.074	.037	.037	.148	.250	.139	.333	.361	.259	.333
311	.194	.222	.194	.194	.306	.167	.056	.194	.278	.444	.194
312	0	.167	.111	.111	0	.139	.139	.222	.028	0	.222
313	0	.111	.111	.111	0	.318	.250	.222	.139	0	.290
314	0	.296	.111	.222	.111	.291	.250	.333	.139	.222	.374
315	0	.074	0	0	.111	.111	.111	.222	.222	.222	.222
316	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
317	.146	.359	.312	.304	.146	.580	.451	.637	.443	0	.663
318	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
319	.146	.378	.312	.304	.146	.580	.451	.637	.443	0	.663
320	.146	.267	.201	.193	.146	.357	.340	.415	.332	0	.441
321	.167	.194	.167	.167	.278	0	0	.083	.111	.389	.083
322	.111	.074	.111	.111	.222	.322	.028	.222	.250	.222	.405
323	.259	.296	.370	.370	.481	.451	.070	.338	.403	.544	.498
324	.259	.296	.370	.370	.481	.452	.070	.338	.403	.544	.498
325	.056	.056	.056	.056	.167	.167	.056	.222	.278	.167	.222
326	.148	.185	.148	.148	.259	.111	0	.185	.222	.370	.185
327	0	.111	.111	0	.111	.417	.194	.444	.528	.278	.444
328	.028	.194	.139	.139	.028	.374	.222	.444	.222	.139	.485
329	.111	.222	.333	.222	.111	.444	.222	.556	.333	.222	.556
330	0	.111	.111	.111	.222	.250	.139	.333	.361	.333	.333
331	.222	.333	.444	.333	.222	.361	.139	.389	.250	.333	.389
332	0	.111	.222	.111	0	.472	.250	.444	.361	.111	.444
333	0	.333	.222	.222	.111	.472	.250	.556	.361	.222	.556
334	0	.111	.111	.111	0	.180	.139	.111	.028	0	.152
335	0	.222	0	.111	.222	.111	0	.222	.222	.333	.222
336	0	.222	0	.111	.222	.139	.028	.222	.250	.333	.222
337	.111	.222	.333	.222	.111	.222	.111	.333	.111	.222	.333

email (EM), mailinglist (ML), newsletter (NL), face to face (F2F), group meeting (GM), tel. conference (TC), presentation (Pr), publication (Pu), telephone (T)

Continued on next page

Table C.2 – *Continued from previous page*

ID	DMS	DSS	EM	ML	NL	F2F	GM	TC	Pr	Pu	T
338	.222	.444	.333	.444	.333	.139	.139	.222	.028	.333	.222
339	0	.167	.222	.111	0	.544	.250	.556	.361	.111	.627
340	.056	.056	.167	.056	.167	.222	0	.278	.333	.278	.278
341	.185	.185	.185	.296	.407	.225	.059	.106	.171	.463	.271
342	.111	.222	.222	.222	.111	.139	.139	.222	.028	.111	.222
343	.222	.222	.222	.222	.333	.139	.028	.167	.250	.444	.167
344	.037	.185	.148	.148	.037	.139	.139	.222	.028	.148	.222
345	.037	.185	.148	.148	.037	.263	.111	.333	.111	.148	.374
346	.111	.056	.222	.111	.222	.561	.175	.480	.508	.281	.644
347	.037	.074	.037	.037	.148	.028	.028	.074	.139	.259	.074
348	.028	.194	.139	.139	.250	.339	.028	.333	.361	.361	.422
349	.028	.083	.028	.028	.139	.339	.139	.333	.361	.139	.422
350	.028	.194	.139	.139	.250	.339	.028	.333	.361	.361	.422
351	.111	.185	.111	.111	.222	.152	0	.222	.222	.333	.263

Table C.2: Dissimilarity coefficients $d_{C,M}$ for all conversation/medium matches.

Curriculum Vitae

JAN TIM JAGENBERG

2008 – 2013 Department of Computer Integrated Design
Technische Universität Darmstadt, Germany
Research Assistant

2001– 2007 Studies of Aerospace Engineering
Universität Stuttgart, Germany
Degree: Diplom Ingenieur

2007 Institute of Aircraft Design (IFB) & Engineous Software, Inc.
Universität Stuttgart, Germany & Atlanta, GA, USA
Thesis: Dimensional Analysis in Data Approximation

2006 Institute for Statics and Dynamics (ISD)
Universität Stuttgart, Germany
Thesis: A Generic Framework for Evolutionary Optimisation in Rule-Based Design

1991– 2000 Eduard-Spranger-Gymnasium, Filderstadt, Germany
Degree: Abitur